

PLANKTON OF THE FLORIDA CURRENT
V. ENVIRONMENTAL CONDITIONS,
STANDING CROP, SEASONAL AND DIURNAL
CHANGES AT A STATION FORTY MILES
EAST OF MIAMI¹

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ABSTRACT

This is a survey of the standing crop of plankton in the Florida Current, its vertical, seasonal and diurnal changes, and of relevant environmental conditions. The top 100 meters is considered to be the euphotic zone. Most of the phytoplankton is nanoplankton and is concentrated in the euphotic zone, where it shows some seasonal change. Zooplankton also show a small seasonal change and a marked diurnal migration in the euphotic zone. Details are given for siphonophores, chaetognaths, copepods, euphausiids, pteropods and young fish. There is some seasonal fluctuation in the total phosphorus content of the euphotic zone, and most of the phosphorus is in the form of dissolved organic matter. A smaller fraction comprises live nanoplankton and detritus, and a very small fraction is due to zooplankton. Both the inorganic phosphorus and inorganic nitrogen are extremely deficient at all times in the euphotic zone.

INTRODUCTION

The majority of the quantitative plankton studies along the eastern coast of the United States have been limited to northern waters, that is, from Chesapeake Bay north to Maine. Some scattered data are available for the area off the Florida East Coast where the Gulf Stream makes its closest approach to the American mainland.

Parr (1933, 1937) reported on the hydrographic conditions in the Gulf of Mexico and the Straits of Florida. An excellent summary of these and later investigations on the hydrographic conditions of the Gulf of Mexico and adjacent areas has been prepared by Leipper (1954). Riley (1937) studied phytoplankton production in Gulf of

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Mexico waters, where he considered the influence of the Mississippi River drainage in the northern portion of the Gulf. Analysis for plant pigments showed that phytoplankton productivity was highest in waters richest in phosphates. However, samples obtained from completely fresh river water produced higher values for plant pigment than those obtained elsewhere, but these values are not high for typical fresh water indicating that the high turbidity of the river water interferes with plankton production. Analysis of open Gulf water showed typically low values. Later work by Riley (1938) was done in the Dry Tortugas area at the end of the chain of the Florida Keys where the waters emerging from the Gulf of Mexico join the Florida Current. He found that in the waters of the Tortugas region, the nitrates were more important than the phosphates as limiting factors in phytoplankton production.

Smith, *et al.* (1950) conducted an ecological survey of Biscayne Bay, adjacent to Miami. The results of this survey indicate that a large role is played by land drainage and sewage in the growth of plankton and sedentary organisms and that the year around plankton growth is limited by the rate of phosphate production and a grazing rate limited by phytoplankton formation.

Miller, *et al.* (1950) conducted investigations of the Florida Current at a station 10 miles east of Miami. They found that peak values of the phytoplankton concentrations generally succeeded those of the nutrients, while those of the zooplankton were less clearly related. An extremely high ratio of the filterable nannoplankton to net caught phytoplankton was found to be typical for this area.

In 1953, the Marine Laboratory, University of Miami, commenced a study of productivity in the Florida Current off Miami. The initial phase of this survey was planned to measure the standing crop of the zooplankton and phytoplankton along with the available inorganic and organic nutrients and such environmental factors as temperature, salinity, and illumination. It also was designed to define the vertical distribution and possible seasonal variations of these organisms. If, as proved to be the case, the seasonal variations are small, Riley's method of regression would not be applicable to this phase of the work. The products of this investigation are here reported together with a discussion of various aspects of the biological system. The tables of data are too lengthy to be included in the text and are on deposit at the Marine Laboratory, University of Miami. Some of the data included have been derived from other but related investigations, in-

cluding work of graduate students.

Some hydrographic information has been made available from studies of the area under Office of Naval Research contracts and National Science Foundation grants, and information on plankton under National Science Foundation and National Geographic Society grants. For several plankton groups masterate or doctorate theses are referred to. Some of these results are as yet unpublished and the workers concerned have generously allowed us to include data extracted from their studies. They include D. O'Berry and E. C. Jones (Copepods), R. L. Wormelle and T. Dow (Pteropods), D. C. Roane and H. B. Moore (Siphonophores), H. Owre (Chaetognaths), N. Voss, G. L. Voss, J. Clancy, V. A. Legaspi (Fish Larvae), G. L. Voss (Cephalopods), and J. B. Lewis (Euphausiids).

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Many members of the staff of the Marine Laboratory have from time to time contributed assistance and advice. To all of those we wish to express our gratitude. The present paper is published under the name of a single author since joint authorship of all who have participated would have been hardly feasible. He wishes to make it clear that he has acted as compiler of the results and as chemist in the last phases of the work, but that credit is due to many others also.

PHYSICAL AND CHEMICAL CONDITIONS

Temperature and Salinity

Samples for this study were collected at a routine station approximately four miles west of Gun Cay ($25^{\circ}33' \text{ N.} - 79^{\circ}25' \text{ W.}$), where the depth of the Florida Current is over 700 meters. During the course of the collection, it was impossible to hold an exact station due to the strong currents encountered. It was necessary to interrupt the collection operation numerous times in order to return to the station. In

spite of the above difficulty, the samples were collected in an area a few miles in diameter.

The station was occupied approximately once every month during the initial year. However, due to weather conditions and other factors, it was frequently necessary to delay the cruises for longer intervals. During the following year, the station was occupied less frequently, mainly to check for variations and for collection of miscellaneous data.

Temperature measurements at the station were made with a 900 ft. bathythermograph and reversing thermometers attached to Nansen bottles. Surface temperatures were measured with a bucket thermometer.

Water samples for salinity determinations and other chemical analyses were collected with Nansen bottles placed at 50 meter wire intervals. Salinities were determined by titration according to the Knudsen silver nitrate method.

Figs. 1 and 2 show the extreme range of temperatures encountered in the Florida Current off Miami. As one would expect, the upper

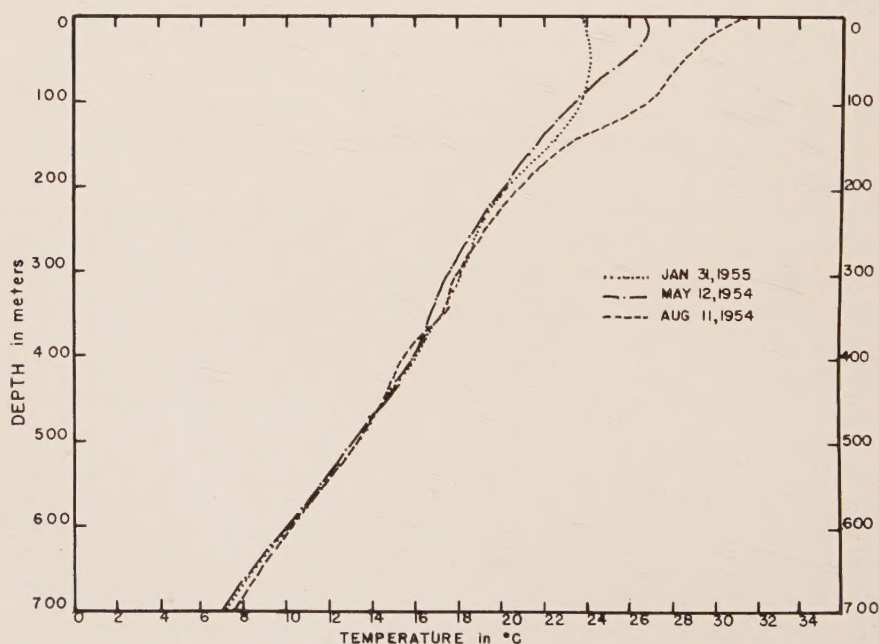


FIGURE 1. Typical vertical distribution of temperature encountered in the Florida Current, showing the extreme fluctuations.

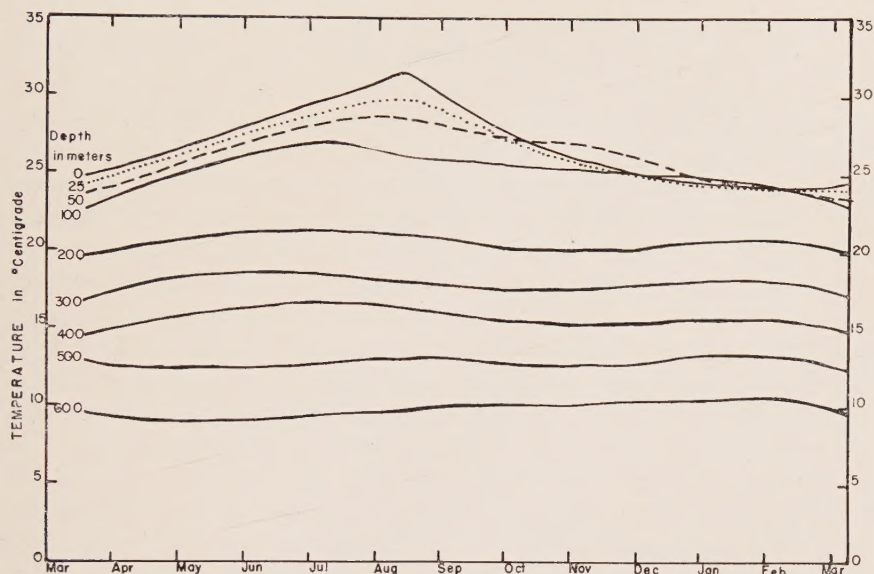
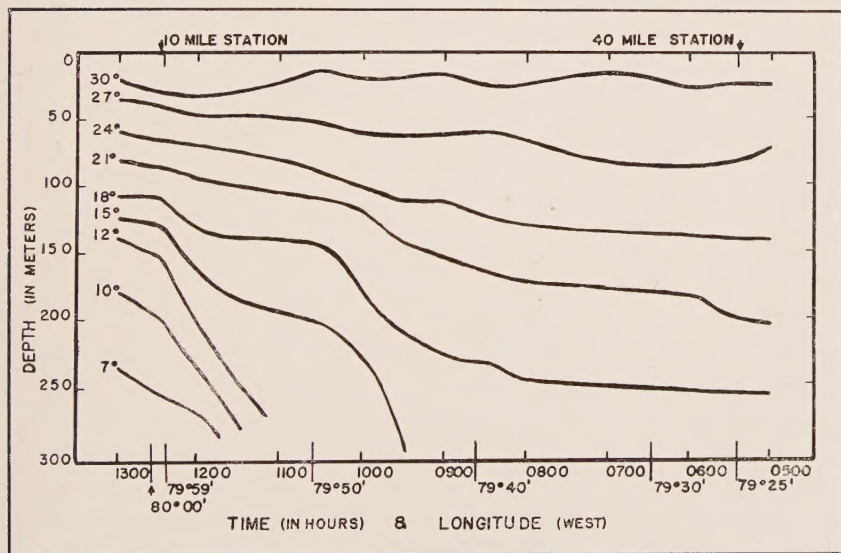


FIGURE 2. Seasonal variation of temperatures at constant depths.

FIGURE 3. Temperature profiles across the Florida Current, at $25^{\circ}33'$ N. Lat., during the summer months.

surface waters show considerable variation during the yearly cycle. At depths below 150 meters, the temperature remains fairly constant. The maximum surface temperature of $31.4^{\circ}\text{C}.$ was recorded during the August cruise, the lowest, $23.8^{\circ}\text{C}.$; during the February cruise. This temperature range is in good agreement with that obtained by Miller, *et al.* (1953) for the 10 mile station off Miami. Fig. 3 shows the variation of the isotherms in a typical section across the Florida Current from Miami to Gun Cay. The isotherms on the western side, where the depth is approximately 300 meters, are more closely packed.

The T-S and S-D curves (Figs. 4 and 5) resemble those obtained by Miller (1953) and Lewis (1954). According to the work of Parr (1933), the water mass of the Florida Current is composed of waters from the Gulf of Mexico and the Yucatan Channel. Typical temperature-salinity curves are given for these water masses; however, he has shown that when the Gulf Water is present it is limited to a shallow layer and usually extends only a short distance across from the Miami shore. The temperature-salinity curve obtained at our Forty-Mile Station is typical of that obtained by Parr for the Yucatan Channel. This

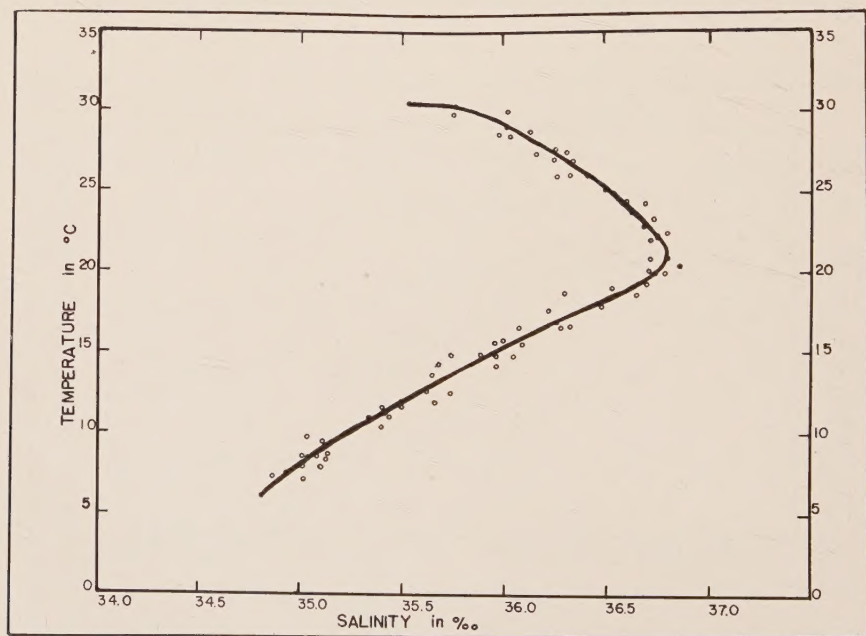


FIGURE 4. Temperature-salinity relationship of the water forming the Florida Current.

water mass remains fairly constant throughout the year as indicated by the slight scattering of the points in both Fig. 4 and 5.

Light

Light transmission in the Florida Current is generally high; the Secchi disc reading is, on the average, around 33 meters. Figure 6 shows the seasonal variation of the extinction coefficient as calculated from the maximum depth of visibility of the Secchi disc. The isolume, which corresponds to 1.0% of sunlight when measured against full sunlight at the surface at noon, is also shown in Fig. 6, and is considered the lower limit of the euphotic zone. This zone appears to oscillate around the 85 meter depth. However, since only a small error will be introduced and since some authors use 0.5% sunlight as an estimate of the compensation depth the euphotic zone throughout this paper has been taken as 100 meters.

Oxygen

Oxygen was determined on several occasions by the Winkler Method. A portion of this data is shown in Fig. 7, as vertical distributions. No special attention or prominence was given to this factor since oxygen concentration never drops low enough to be likely to affect the animals.

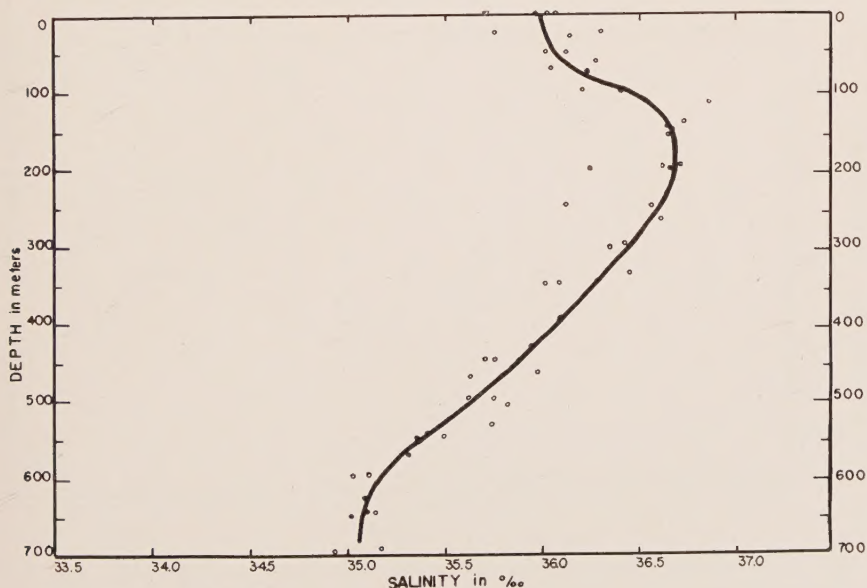


FIGURE 5. Salinity-depth relationship of typical Florida Current water.

Nitrates and Phosphates

Nitrate analyses were carried out in two steps. The initial operation consists of reducing, quantitatively, the nitrate to nitrite using the method of Føyn (1951). The nitrite is then determined by the spectrophotometric method of Bendschneider and Robinson (1952).

Figs. 8 and 9 show the seasonal distribution of the dissolved nitrates occurring in 1955 and 1955. In Fig. 9, it is readily observed that the immediate surface waters remain at very low levels, less than 5 microgram-atoms per liter, throughout the entire year. The large change in the nitrate concentration which occurs for some temperate waters as reported by Riley (1949, 1956) are not present for these subtropical waters. A small build-up of nitrate appears to occur in the early autumn at approximately the 100 meter level. Values of 6 to 10 microgram-atoms per liter form a large band in the intermediate zone that appears to remain constant throughout the year. However, from October to February a large tongue of water of this nitrate concentration

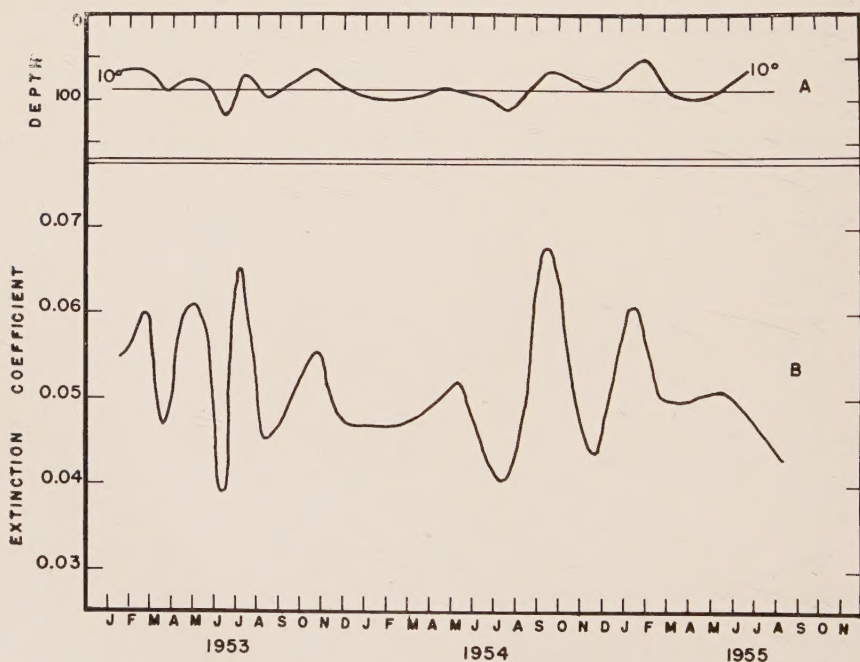


FIGURE 6. (A) Seasonal variation of the isolume corresponding to the limit of the euphotic zone. (B) Seasonal variation of the extinction coefficient of the Florida Current.

extends to the deepest layers. Generally at depths of 300 meters and lower there appears to be no set pattern of variation, the picture becoming rather erratic.

The dissolved inorganic phosphorus analyses were carried out according to the colorimetric method of Greenfield and Kalber (1954). The reagent, containing sulfuric acid, ammonium molybdate, and ascorbic acid stored separately, was mixed just prior to use. The color intensity was measured in a Beckman Quartz Spectrophotometer at a wave length of $820\text{ m}\mu$, using either 10 cm. or 1 cm. cuvettes.

The total phosphorus which includes the inorganic, soluble organic and particulate organic phosphorus was determined by first oxidizing the sample with perchloric acid using the method described by Hansen and Robinson (1952). After digestion, the sample was treated as described for the dissolved inorganic phosphorus.

Figs. 10 and 11 reveal the seasonal, vertical distribution of the dissolved inorganic phosphorus. The concentration of phosphorus in the upper 150 meters is never very high, the value not exceeding 0.2 microgram-atoms per liter. During the summer and fall months, the values drop even lower, to less than 0.1 microgram-atoms per liter. At greater depths, more or less regular ribbons of various concentra-

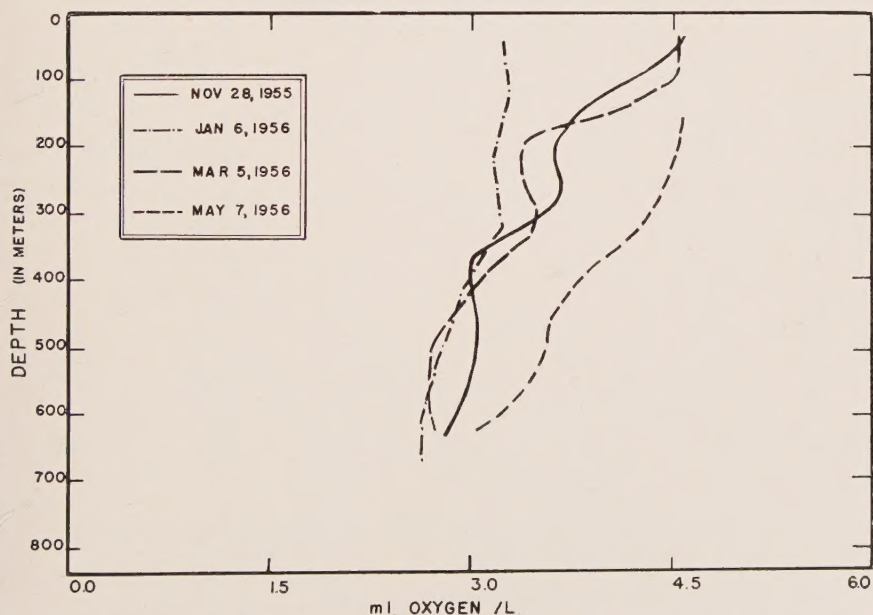


FIGURE 7. Typical vertical distributions of oxygen in the Florida Current.

tions cross the diagram with a steady increase of phosphorus concentration as the depth increases.

The variation of total phosphorus which includes both the bound and unbound phosphorus is shown in Figs. 12 and 13. Here a different picture is presented. The somewhat continuous bands that occur in the dissolved inorganic phosphorus are not observed except in the deeper waters, that is below 400 meters. Above this depth, considerable variation in the total phosphorus concentration occurs throughout the year. During the spring, the total phosphorus concentration is quite low being of the order of 0.5 microgram-atoms per liter or less. As the season progresses into the summer months, a small build-up of phosphorus concentration occurs, the range increasing to 0.5 to 1.0 microgram-atoms. The total phosphorus concentration continues to increase to values ranging from 1.0 to 1.5 microgram-atoms during the autumn months. With the approach of the winter months, the values begin to drop again. Thus the largest concentration appears to occur during the autumn season. It should be noted that during the height of the summer season a pocket appeared in the surface water, reaching a depth of approximately 60 meters, where the total phos-

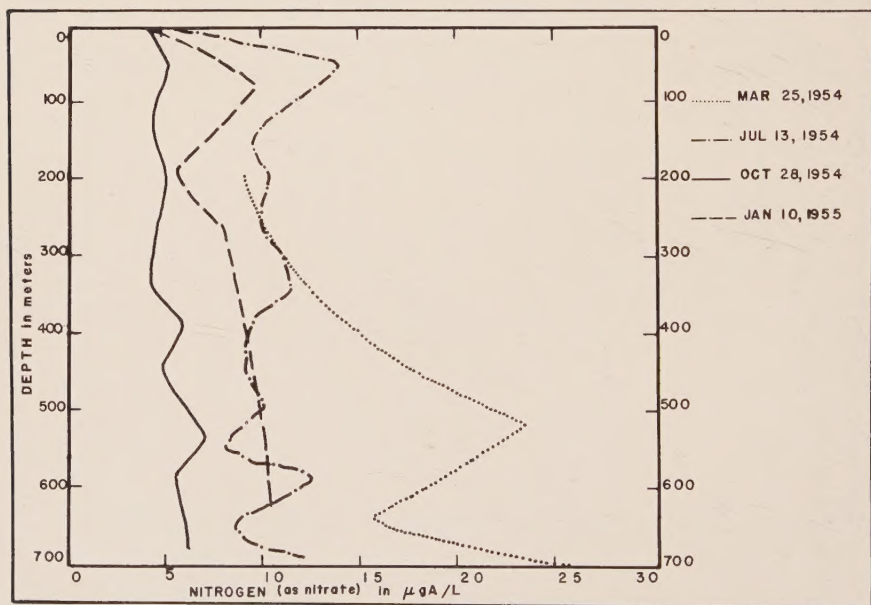


FIGURE 8. Typical vertical distributions of the nitrate-nitrogen in the Florida Current.

phorus concentration increased to a high value of 2.0 microgram-atoms.

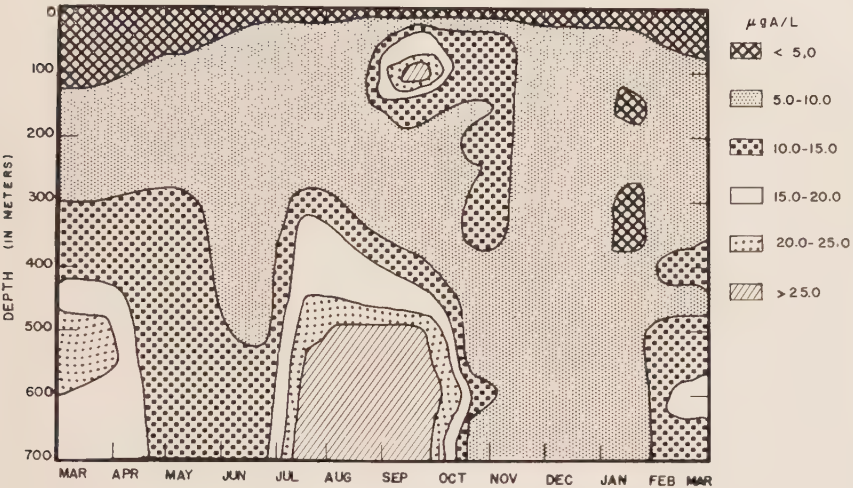


FIGURE 9. Seasonal variation of nitrate-nitrogen in the Florida Current.

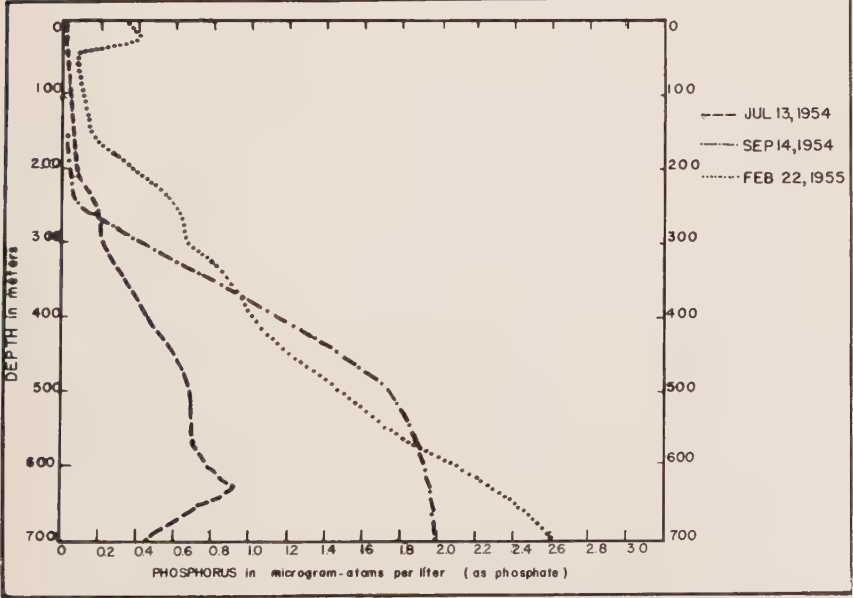


FIGURE 10. Typical vertical distributions of phosphate-phosphorus in the Florida Current.

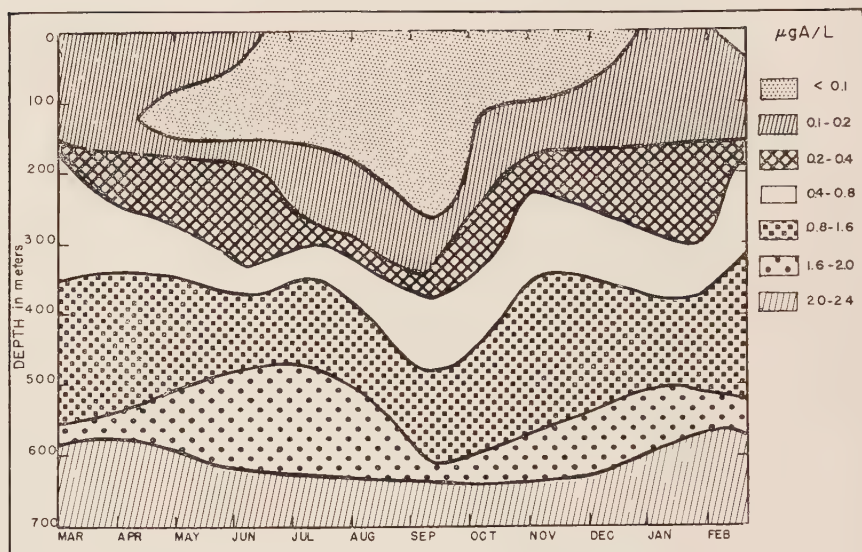


FIGURE 11. Seasonal vertical distribution of phosphate-phosphorus in the Florida Current.

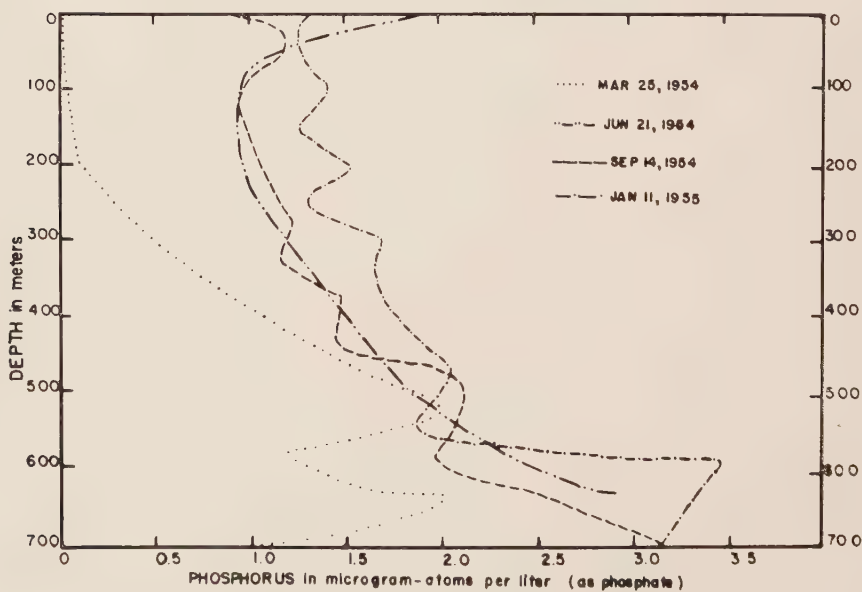


FIGURE 12. Typical vertical distribution of total phosphorus in the Florida Current.

PLANKTON

No attempt was made to study the net phytoplankton in the Florida Current since it has definitely been shown that it is present in very small quantities. Miller and Moore (1953) have shown for this area, that the nannoplankton by weight measurement is consistently about a thousand times as rich as the fraction of phytoplankton which can be collected with a net. Metered Clarke-Bumpus No. 20 net hauls were compared with the results obtained from samples filtered through a No. 54 Whatman filter paper. Therefore, it became clear that the net hauls do not provide an adequate picture of the standing crop of phytoplankton. Hart (1934) demonstrated that the proportion of armored dinoflagellates in the phytoplankton population increase greatly in the lower latitudes as compared to the Antarctic seas. If the nannoplankton are considered to be largely unarmored dinoflagellates, then it would not be unreasonable to suspect that they would constitute a high proportion of the phytoplankton in the warmer waters.

Nannoplankton

The nannoplankton as discussed in this study consist of planktonic forms in the size range of 107 microns or less. No attempt was made at the identification of the species present. Also, no extensive attempts have been made to separate the living material from detritus, which

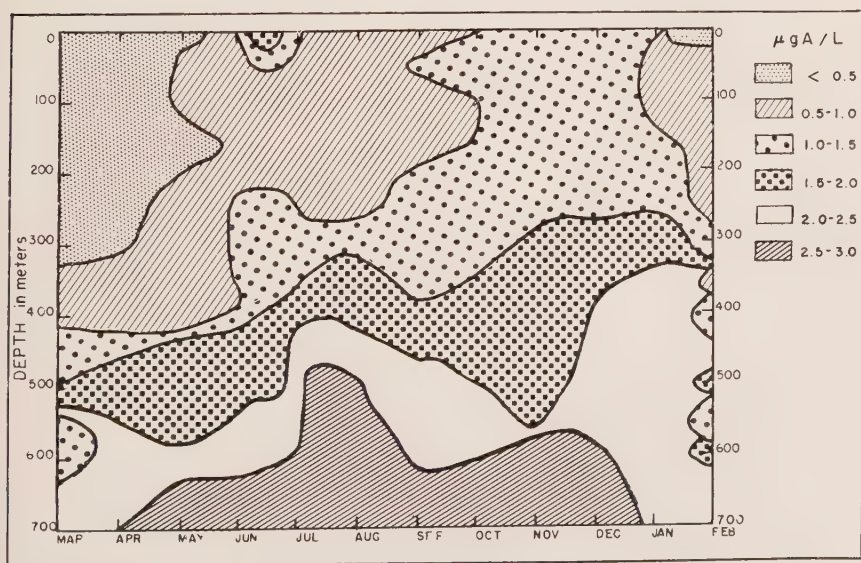


FIGURE 13. Seasonal variation of total phosphorus in the Florida Current.

is believed to be present in only small quantities.

The nannoplankton was obtained by pumping sea water into treated steel drums of 200 liter capacity, after which it was passed through a Sharples Super-Centrifuge running at approximately 23,000 rpm. The macroplankton were eliminated by screening the water through a 107 micron mesh stainless steel screen which was attached at the orifice of the drums. All samples collected in the field in this manner were quick frozen by dipping the container into a dry ice-acetone bath, stored on dry ice and returned to the laboratory for analysis. The use of the centrifugal pump-super centrifuge apparatus was found to be impractical at depths below 600 feet, due to the excessive bulk of the hose and difficulty encountered with the pumping operation.

Dry weights of the nannoplankton were determined by drying the samples by lyophilization and subsequent weighing of the dry material.

The seasonal vertical distribution of the nannoplankton as dry weights are shown in Figs. 14 and 15. It is readily observed in Fig. 15 that a bloom occurs during the summer months, the increase being about seven fold in the upper 35 meters of water at the height of the bloom. The over-all effect of this summer bloom extends slightly beyond the lower limit of the euphotic zone at 100 meters, and extends throughout the autumn months in the upper 40 meters of water.

The general chemical analyses of the nannoplankton samples were

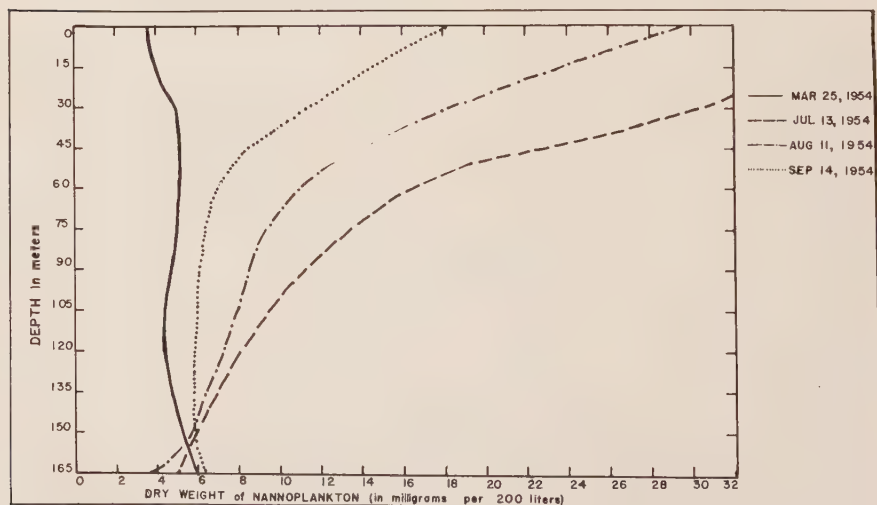


FIGURE 14. Typical vertical distributions of nannoplankton as dry weight.

performed on trichloroacetic acid extracts and the remaining solid residue. These analyses included total phosphorus, nitrogen, carbohydrates, fats and pigments. As these biochemical data of the nanoplankton are as yet incomplete, they will not be presented here.

Zooplankton

The plankton nets used for the collection of the zooplankton were of the "Discovery" type (Kemp, Hardy, and Mackintosh, 1929), with a 70 cm. diameter opening. This net as well as the closing mechanism has been adequately described by Miller, *et al.* (1953). The net is lowered to the desired depth open, but is closed before returning to the surface. It has been shown (Moore, 1949) that the amount of plankton caught at the intermediate depths as the net is being lowered does not introduce a serious error.

The net hauls were made at 100 meter intervals from the surface to the near bottom or 700 meters. Generally two nets were towed simultaneously with a depth-distance recorder (Miller, *et al.* 1953) accompanying one of the nets. In the case of the top pair, a third net was usually towed simultaneously at the surface. The nets were towed for one half hour at the required depth and at a speed of about 2 knots. Owing to the variable currents encountered in this area, it is difficult to control the distance towed, so the readings of the depth-distance

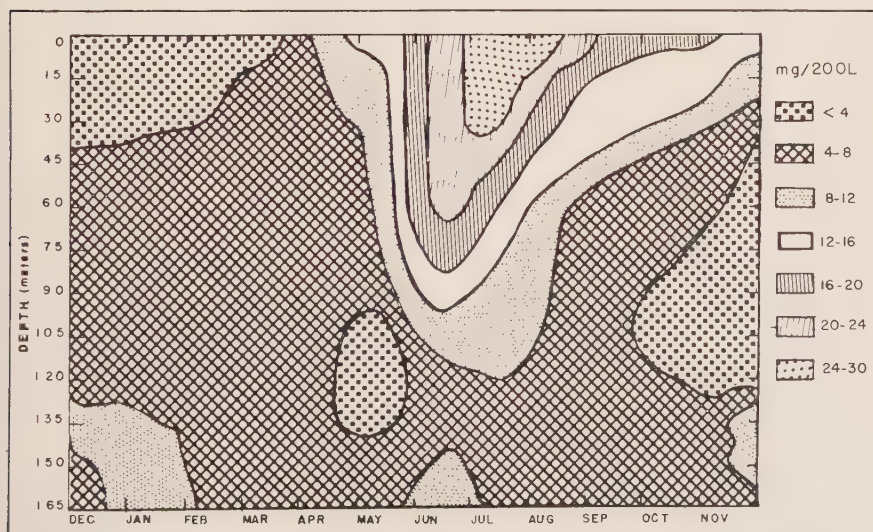


FIGURE 15. Seasonal vertical distribution of nanoplankton as dry weight in the Florida Current.

recorder were applied to the data and all measurements of the catch were corrected to the equivalent of a towing distance of one mile. Upon the completion of each haul the plankton samples were collected in jars and preserved in a 5 percent solution of formalin neutralized with borax.

The basic measurement of zooplankton quantity had to be made as displacement volume. This method is not very satisfactory but is the only rapid method which will allow further examination of the animals. Displacement volumes were determined by straining the plankton sample on a filter composed of No. 20 silk bolting cloth and removing the excess water with absorbent paper. The plankton were then placed into a measured volume of water from which the displacement volume is determined. Examination of the various species of animals present was made by counting.

Seasonal Variation

The first point to establish is the extent of the seasonal variation in the total zooplankton population. Smith, *et al.* (1950) have shown that a small seasonal change occurs at a station on the edge of the reef and also inside Biscayne Bay (Table 1).

TABLE 1

Month	Station 9	Station 5-10
February	0.5	0.9
April	1.0	0.8
June	0.25	0.6
July	0.5	2.0
August	1.0	2.0
October	4.5	3.7
December	2.5	2.6

At the Ten-Mile Station, Miller, *et al.* (1953) have shown the day catches in the top 250 meters were distinctly larger in the February-July period than during the remainder of the year. Unfortunately, there was a gap in the readings for the March-May period and, further, it is possible that some change in the plankton volume may have been associated with the varying proportions of Gulf and Yucatan water masses. The ratio of the mean volume in the February-July period to that of the rest of the year was 1.56 : 1.

The volumes of all the catches at the Forty-Mile Station were first corrected to the equivalent of one mile of towing. Assuming that all the water which passed through the ring of the net was filtered, the plankton content per cubic meter was obtained. By combining the

results at different levels, the total plankton content of a column of water under a surface area of one square meter down to a depth of 600 meters, was determined. Actually less water was filtered because of net resistance, and because the lead section of the nets was of large mesh, but tests made with a meter from a Clarke-Bumpus net, placed at different positions indicated that 70 to 80 percent of the theoretical quantity actually passed through the net. There is also an error due to the more active organisms avoiding the net. The extent of this is unknown. It may be assumed to be a serious error for fishes, cephalopods, decapods and the larger euphausiids. For the coelenterates, smaller crustacea, chaetognaths, salps, etc., the counts probably represent 60 % of the true population. The herbivores, being generally smaller and less active, are probably more correctly estimated than the carnivores.

Fig. 16 shows the seasonal variation in the day plankton volume at the Forty-Mile Station. In 1953 the March-June catches were two to three times those for the rest of the year. For various reasons it was not possible to produce comparable figures for the spring-summer period in other years but the values at other times were in reasonable

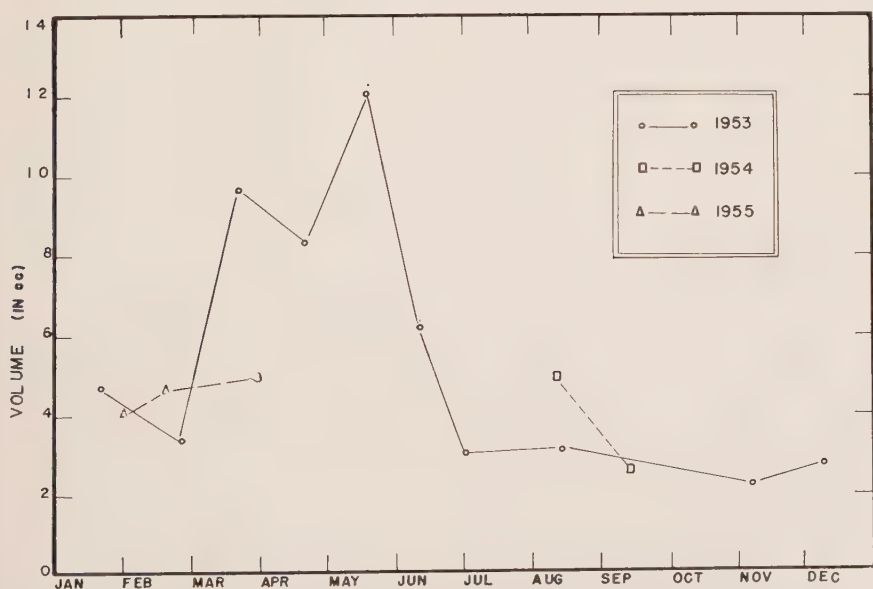


FIGURE 16. Seasonal variation in the day volumes of plankton at the Forty-Mile Station under one square meter to a depth of six hundred meters.

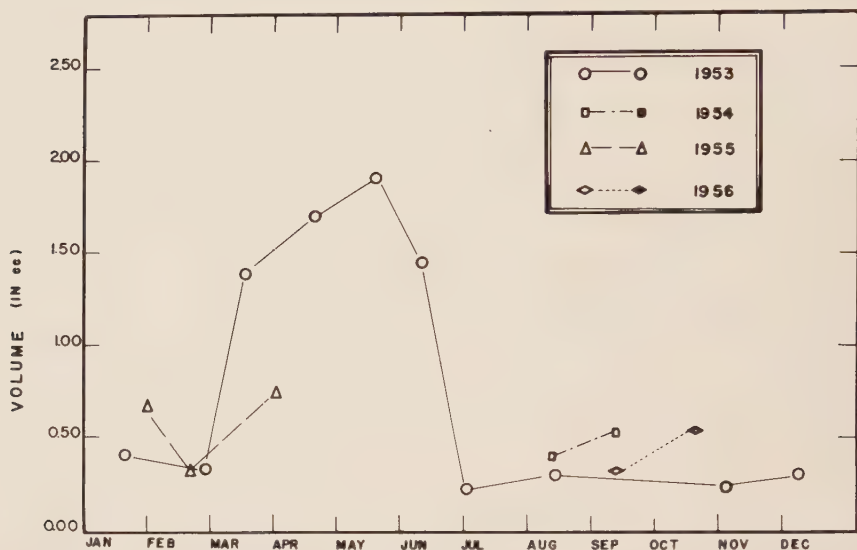


FIGURE 17. Seasonal variation in the day plankton volumes of the euphotic zone at the Forty-Mile Station under one square meter to a depth of one square meter to a depth of one hundred meters.

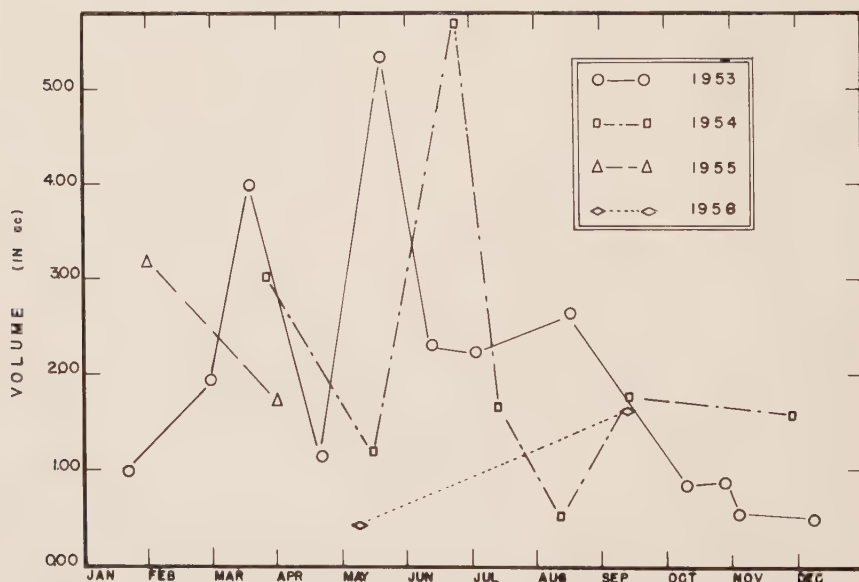


FIGURE 18. Seasonal variation in night volumes of plankton in the euphotic zone at the Forty-Mile Station under one square meter to a depth of one hundred meters.

agreement though perhaps suggesting some yearly differences in the time of the peak.

For the euphotic zone, the top 100 meters, there is a similar increase in plankton volume for the April-June period, the increase being about four fold. The data of 1954 or 1955 are in reasonable agreement with those of the more complete 1953 series as shown in Fig. 17. A better comparison of the two years may be obtained when the night hauls from the euphotic zone are considered since this is a more complete series (Fig. 18). Both years show an early summer increase but this is complicated by shorter periods of fluctuation which are likely to be associated with the effect of varying illumination on the extent of night migrations into the euphotic zone. The system of peaks is rather similar except for a time displacement in the two years. A correlation between peaks and moonlight is doubtful.

Since plankton volumes may give an erroneous impression on account of the varying proportions of such gelatinous forms as medusae, salps, etc., a check on the seasonal cycle was obtained from copepod counts. The data were supplied by D. L. O'Berry from a study of the

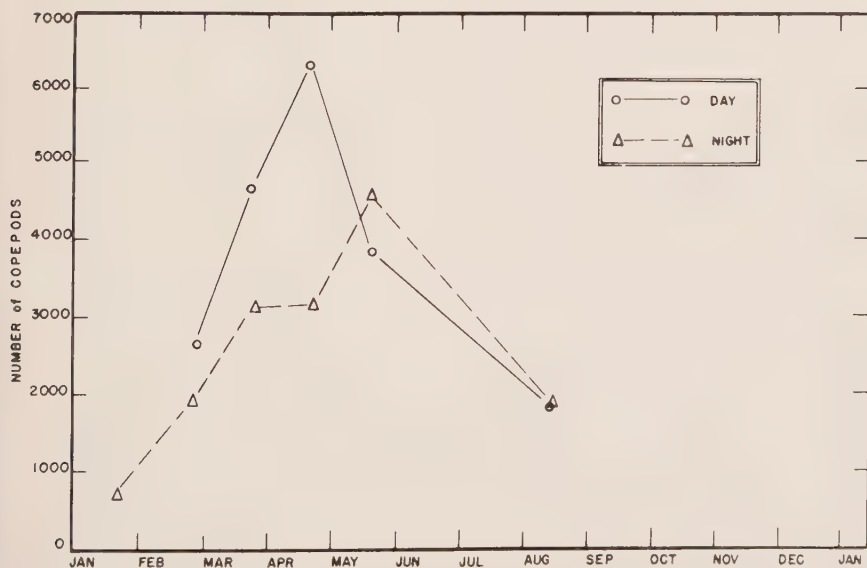


FIGURE 19. Seasonal variation in the number of copepods at the Forty-Mile Station. Day values are the numbers under one square meter to a depth of six hundred meters. Night values are the numbers under one square meter to a depth of five hundred meters.

factors controlling diurnal migration. They were treated in the same way as the volume data and in this case, there is no significant error due to escape (Fig. 19). Although they do not cover the entire year, the results confirm the position of the peak in the spring with a value of two to three times of that later in the year.

It is interesting to note that in Bermuda (Moore, 1949) the total volume of zooplankton showed a maximum in May-June and a minimum in October, with the maximum being about twice the value of the minimum. This fluctuation was attributed to a seasonal change in the current system, later confirmed by Hela and Moore (1953). However, if a part of this change represents a true seasonal variation, its cycle would be in agreement with that found in the present work.

Confirmation of the spring peak can be obtained from the total night plankton down to 600 m. although it is to be expected that they will show some fluctuations in relation to the varying conditions of moonlight (Fig. 20). Similarly, Fig. 19 shows the night values for copepods; these also confirm the seasonal peak shown in the day hauls. It should be noted that owing to the inadequacy of the deepest hauls in the night series, copepod counts have been made to 500 meters only. The day hauls were taken to 600 meters. An appropriate allowance

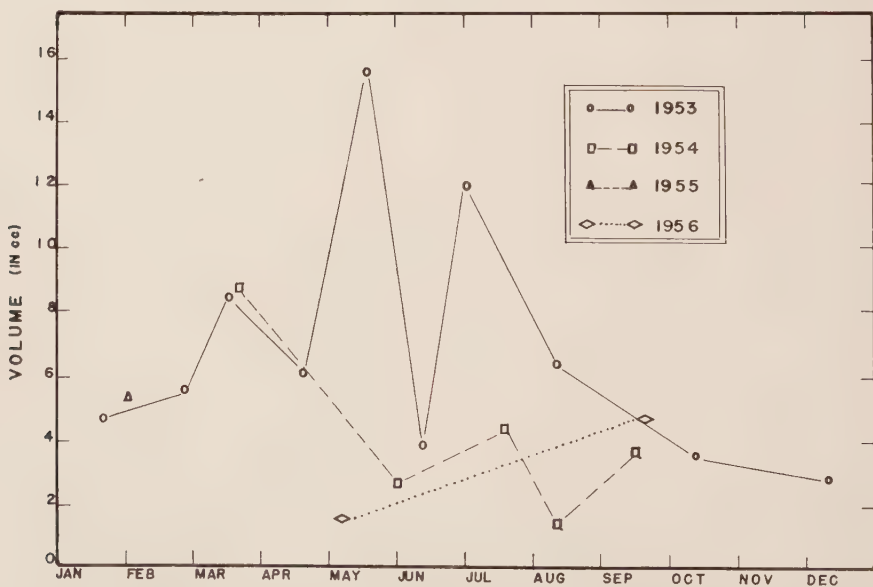


FIGURE 20. Seasonal variation of night (20-04 hr.) plankton volumes at the Forty-Mile Station under one square meter to a depth of five hundred meters.

must therefore be made if the day and night results are to be compared quantitatively.

Diurnal Migration

A considerable proportion of the zooplankton descends below the euphotic zone during the day. For a study of productivity, it is therefore essential to know the diurnal variation in the herbivore population in this zone. By grouping together the data from all stations, we obtain the results shown in Fig. 21. This represents the volume per mile towed, which is equivalent with the assumption referred to earlier to 600 m³ of water filtered.

Although the figure is somewhat patchy, it is clear that there is a very marked diurnal migration of the plankton as a whole, affecting the entire water column sampled. Further, the asymmetry indicates a time lag in the upward movement in the evening so that, although there is indication of the ascent as early as 15 hours below 600 meters, the surface concentrations are from 2100 hours to as late as 0900 hours.

In Fig. 22 we have grouped together as night values all readings between 1800 and 0600 hours. It will be seen that below about 100 meters the night values are approximately one third greater than the day values down to around 350 meters; between 350 and 500 meters

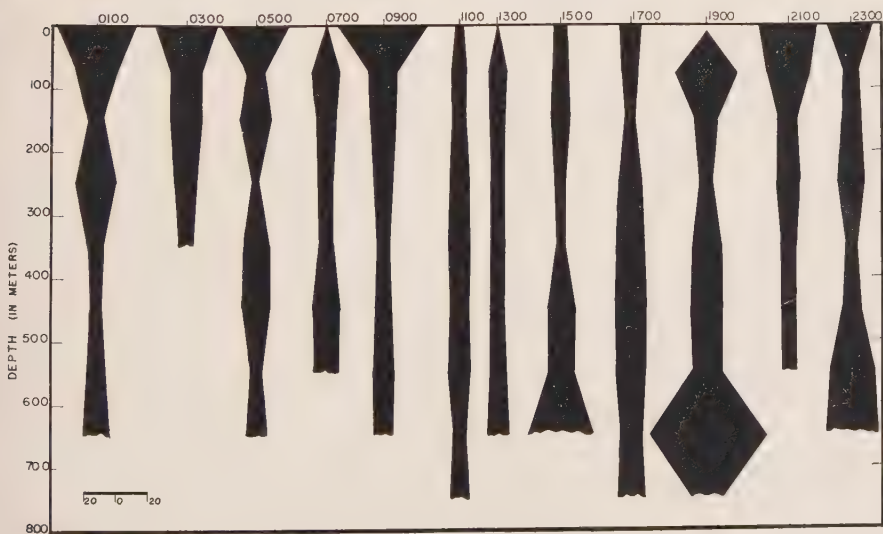


FIGURE 21. Vertical distribution of plankton volumes at the Forty-Mile Station, showing the diurnal migration.

the values are nearly equal, and from 500 to 700 meters the night values are again about one third greater than the day values. In the

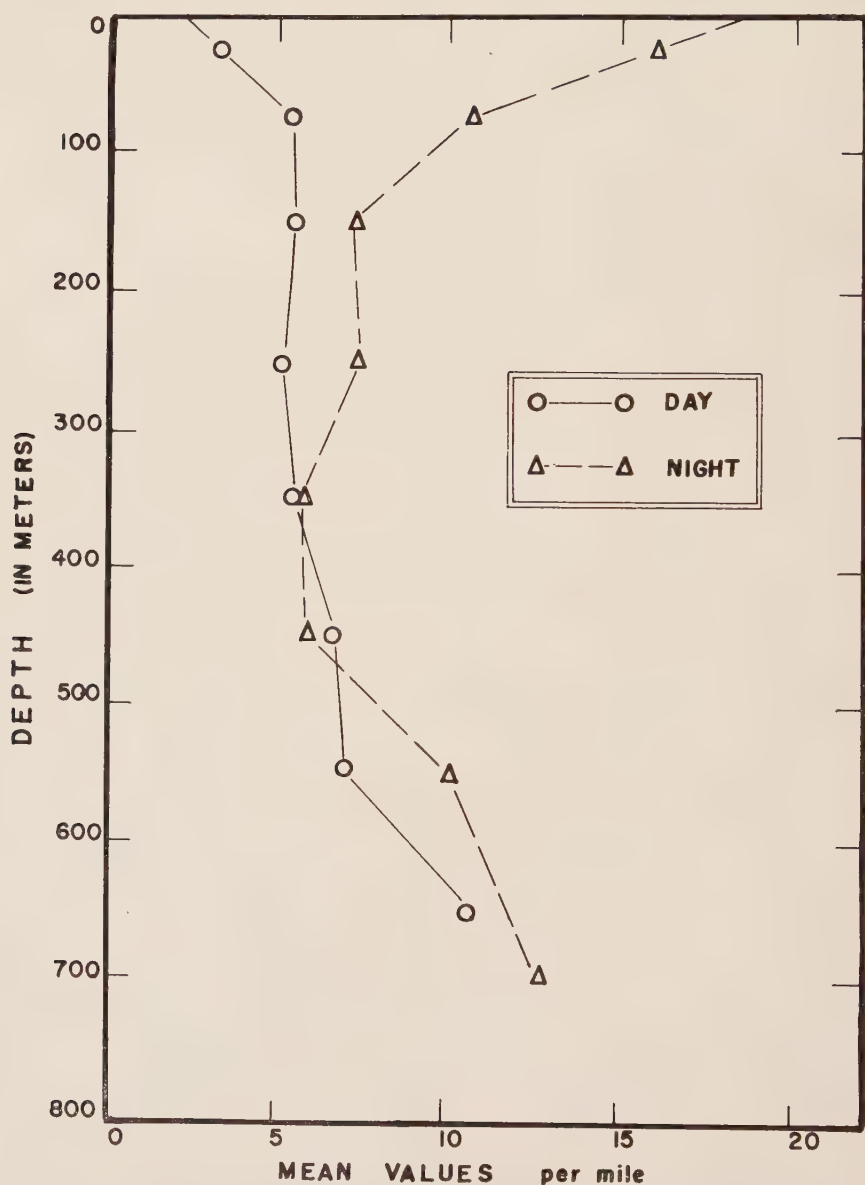


FIGURE 22. Vertical distributions of plankton volumes in cubic centimeters per mile tow at the Forty-Mile Station. Day (10-16 hr.), Night (18-06 hr.).

top hundred meters, which we are considering as the euphotic zone, the increase is about two fold.

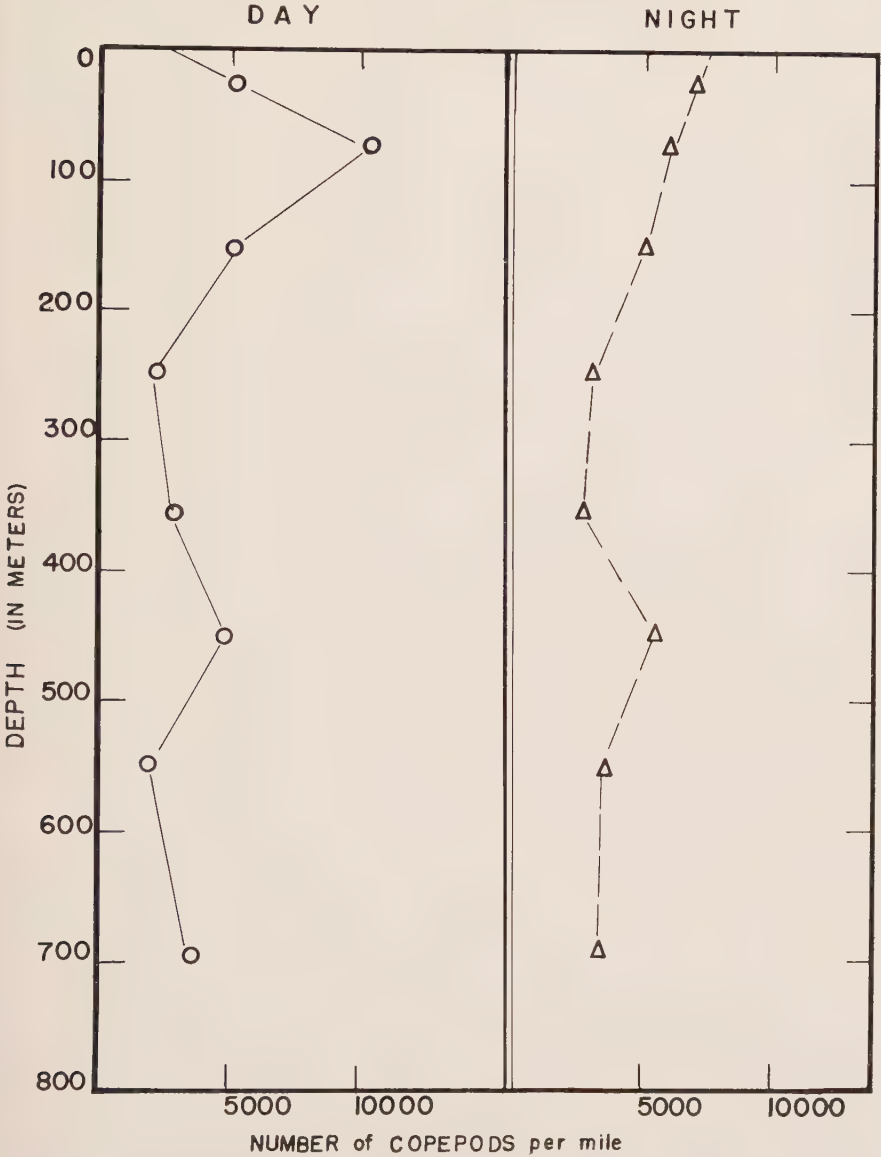


FIGURE 23. Vertical distribution of copepods as numbers per mile tow at the Forty-Mile Station. Day (10-16 hr.), Night (18-06 hr.).

The extent of the diurnal migration varies considerably in the different groups of animals. As a result, there may be a considerable diurnal variation not only in the quantity of plankton at a given level, but also in its constitution. For the various groups studied, we have therefore presented first the diurnal change in vertical distribution and then the day and night graphs showing the number of individuals of each group per cubic centimeter of plankton sample at the different levels.

Copepods

Bermuda data (Moore, 1949) showed a definite diurnal migration of copepods as a whole but unfortunately lacked hauls in the midday period. The present data on copepods are based on counts by D. L. O'Berry. Fig. 23 shows that at the Forty-Mile Station there is no significant diurnal change in number below 150 meters, although we know that some individual species migrate farther than this. Within the euphotic zone there is no significant diurnal change in total number, but a shift in level so that the copepods are predominantly in the lower part during the day, and the upper part at night.

Because the copepods execute less diurnal migration than the rest of the zooplankton (Fig. 22) they become relatively more important in the euphotic zone in the daytime and in the deepest layers at night (Fig. 24). In the euphotic zone, there are twice as many copepods per cubic centimeter of total plankton during the day as there are at night. Below 100 meters there is a slight increase at night.

Although copepod numbers stay relatively constant in the euphotic zone, there is, as described later, a change in weight. This is associated with the fact that some of the smaller species move downward at night and are replaced by larger species moving upwards.

Pteropods

Most of the information on pteropods is based on counts made by T. Dow on material from the Ten-Mile Station. These were published in part by Moore, *et al.* (1953). One Forty-Mile Station has been examined by Mrs. R. Wormelle and is unpublished. At the Ten-Mile day station (Fig. 25) and at both the day and night Forty-Mile Station (Fig. 27) the pteropods are most abundant near the surface with a marked drop just below the euphotic zone and a gradual increase in numbers downward below that level. Owing to hydrographic differences already referred to, the vertical pattern is compacted into a smaller range than at the Forty-Mile Station. Practically all the pteropods caught were Thecosomata. Of these, the species of *Limacina* are so much smaller than all the others that it seemed advisable to consider

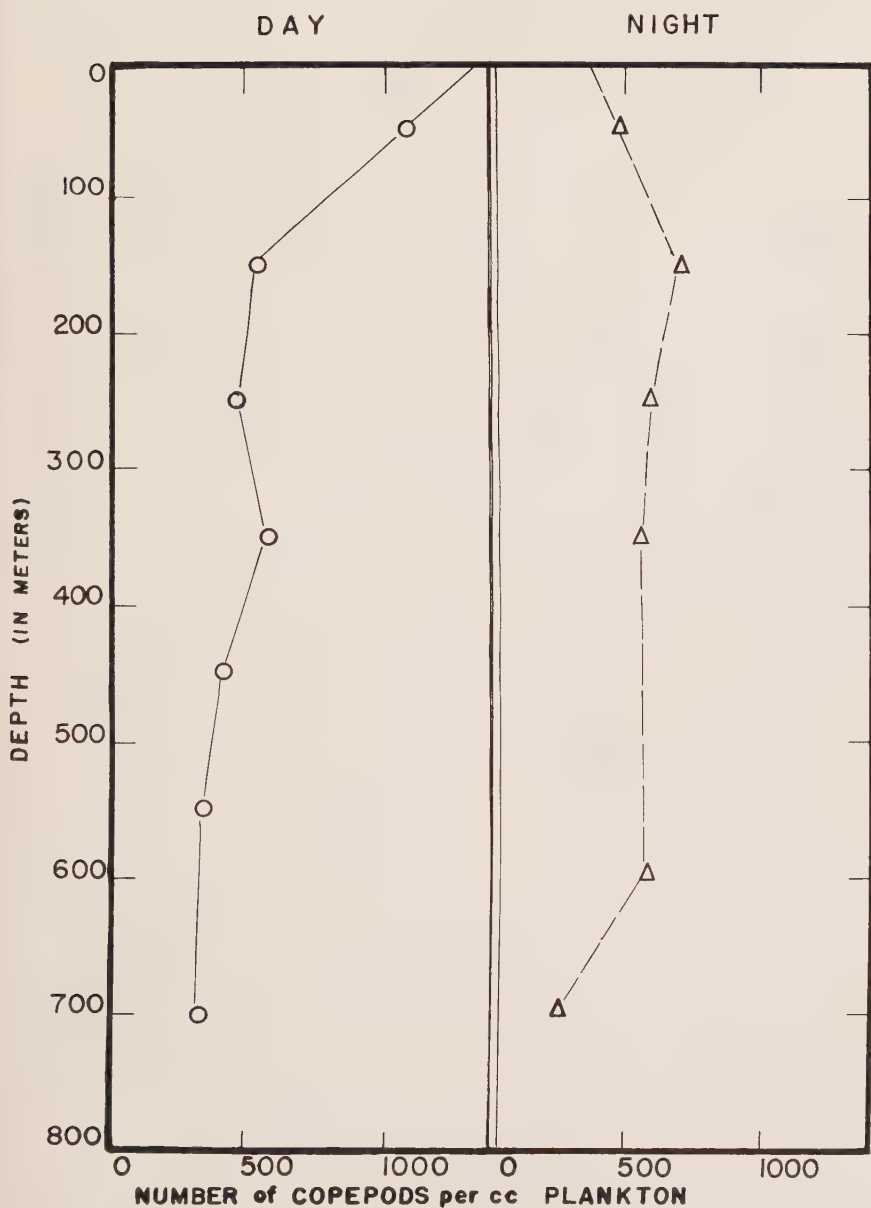


FIGURE 24. Vertical distribution of the number of copepods per cubic centimeter of plankton, showing the diurnal change in the constitution of plankton at the Forty-Mile Station. Day (10-16 hr.), Night (18-06 hr.).

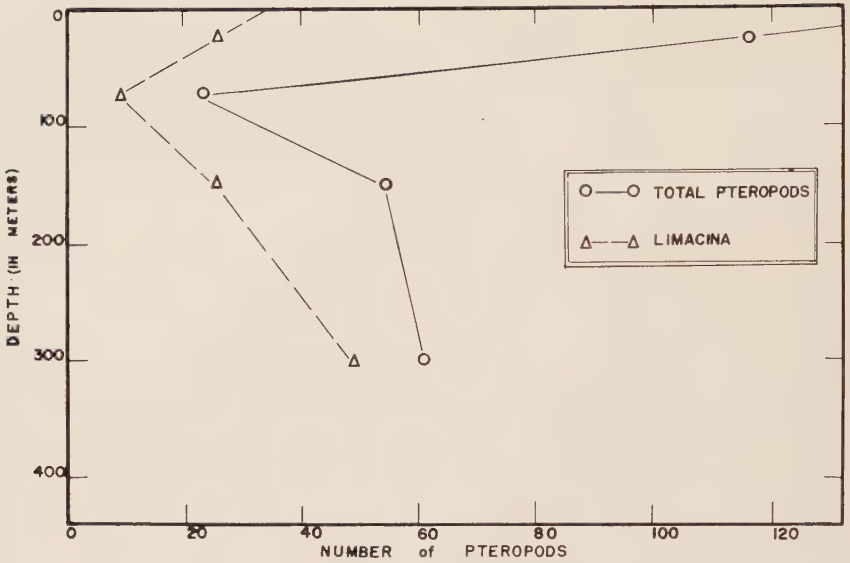


FIGURE 25. Day vertical distribution of pteropods as numbers per mile tow at the Ten-Mile Station.



FIGURE 26. Vertical distribution of total pteropods at one Forty-Mile Station, showing diurnal migration.

them separately. *Limacina* constitute about half of the total pteropods, numerically, at the Ten-Mile Station and rather more at the single Forty-Mile Station. By weight they are almost negligible fractions.

A diurnal migration has been shown for two species of pteropods in Bermuda (Moore, 1949). The results for the single Forty-Mile Station show a very pronounced diurnal migration of both total pteropods and *Limacina* species (Figs. 26 and 27).

The night increase in total pteropods is about nineteen fold in the top 100 meters and about four fold for each increment of depth of the total water column down to 650 meters. Thus the euphotic zone receives a very great increment of the pteropods and a large fraction of those pteropods which ascend from below 800 meters do not approach the actual surface layer. It must be remembered that these deductions are made from the results of one twenty-four hour station only and might need some modification if more data were available.

Fig. 28 shows the number of pteropods per cubic centimeter of plankton. If we may judge from the single Forty-Mile Station examined, they constitute relatively less of the plankton there than at the Ten-Mile Station. They also constitute more of the plankton at night than in the daytime, almost five times in the euphotic zone and three times in the whole column down to 650 meters.

Chaetognaths

H. Owre has studied the chaetognaths at the Ten-Mile-Station. Fig. 29 shows the very strong diurnal migration and Fig. 30, the day and night vertical distribution. The night population is nearly five times the day population in the euphotic zone and about twice in the column down to 350 meters and approximately equal throughout the deeper layers. The day vertical distribution at the Ten-Mile Station (Fig. 31) is similar to that at the Forty-Mile Station but vertically compacted and with larger numbers. The double peaks, one in and one below the euphotic zone, appear at both stations. The number per cubic centimeter of plankton (Figs. 31 and 32) show a double peaking with the day values of the same order at the two stations. At night at the Forty-Mile Station, there was a considerable drop in number per cubic centimeter (the night value being about half of the day value in both the euphotic zone and in the entire column down to 650 meters). A distinction was made (Fig. 32) between the large species, *Sagitta hexaptera*, *S. lyra*, and *S. enflata*, and the remaining smaller species, but the behavior of the two groups appeared similar.

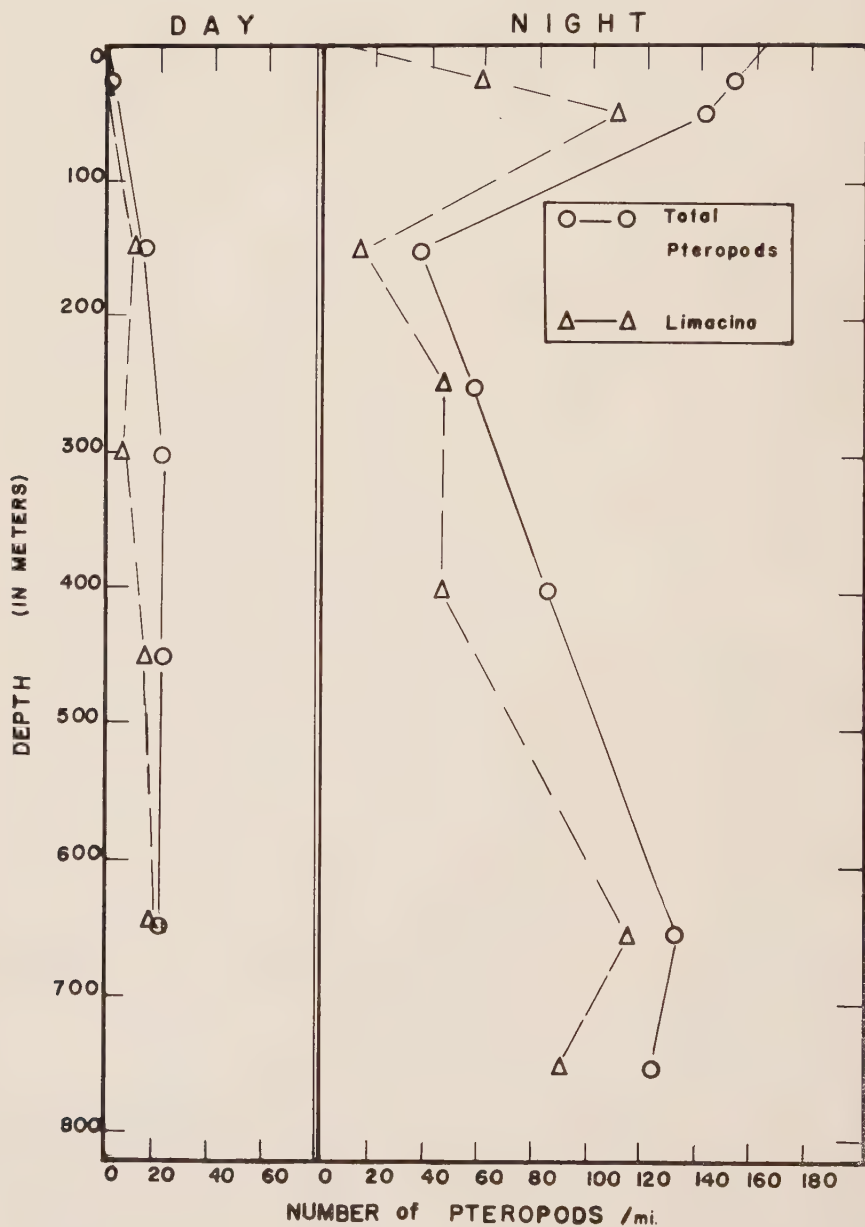


FIGURE 27. Vertical distribution of pteropods at one Forty-Mile Station.
Day (08-16 hr.), Night (20-04 hr.).

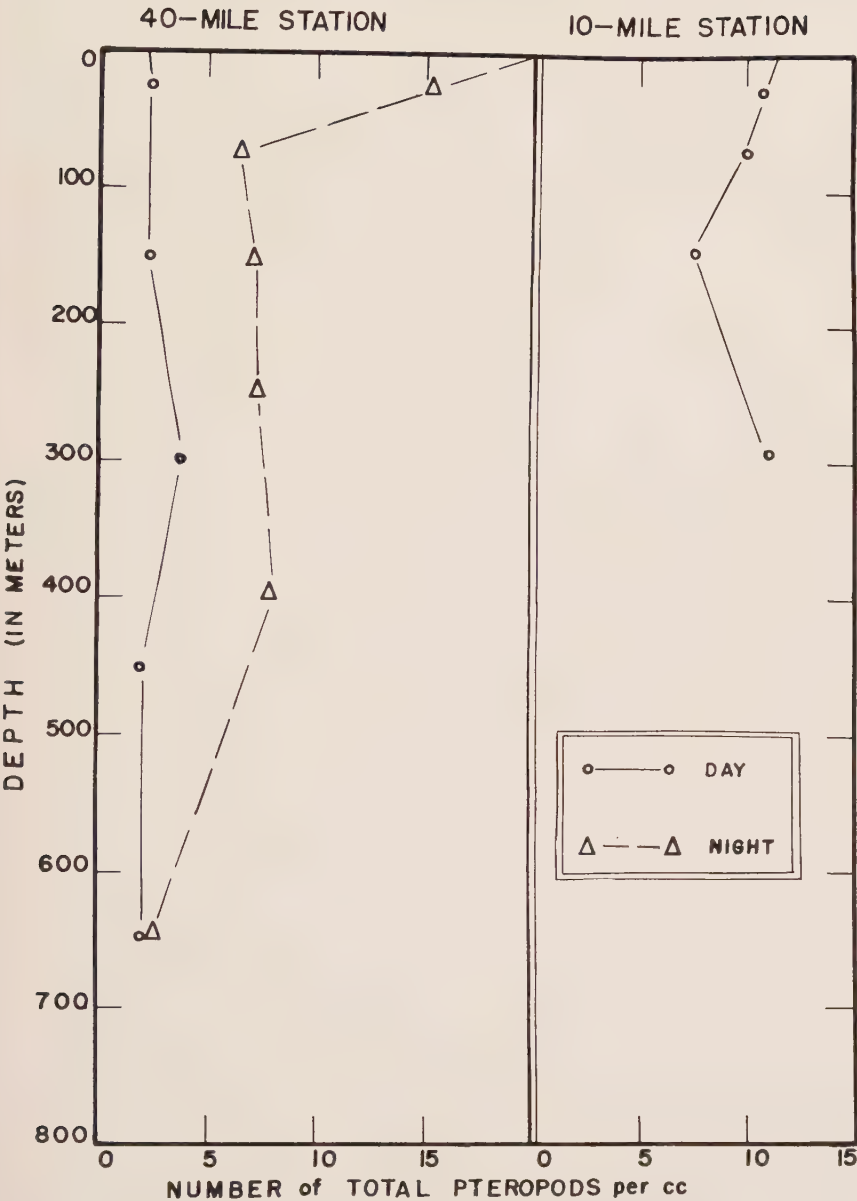


FIGURE 28. (A) Vertical distribution of total pteropods per cubic centimeter of plankton at one Forty-Mile Station. Day (08-16 hr.), Night (20-04 hr.). (B) Vertical distribution of total pteropods per cubic centimeter of plankton at the Ten-Mile Station.

Euphausiids

Lewis (1954) has published an account of the euphausiids at the Forty-Mile Station. The escape factor is undoubtedly serious in this group, so quantities given can only be considered minimal. Some members of the genus *Stylcheiron* differ from the rest of the euphausiids in being very shallow-living and having rather doubtful diurnal migration. *S. carinatum* is by far the commonest species of *Stylocheiron* at the Forty-Mile Station. It is a smaller species than most of the others. Therefore the counts of *Stylocheiron* have been treated separately from those of the remaining euphausiids.

There is a marked diurnal migration in both *Stylocheiron* and the other euphausiids (Fig. 33). In the former, there is a day concentration just below the euphotic zone, while the day descent is greater in other genera. Fig. 34 shows the day and night vertical distribution of the two groups. The euphotic zone shows about a six fold, night increase in *Stylocheiron* and about an eight fold increase for the other genera. The entire column down to 650 meters shows about a two fold increase in each case (Fig. 35).

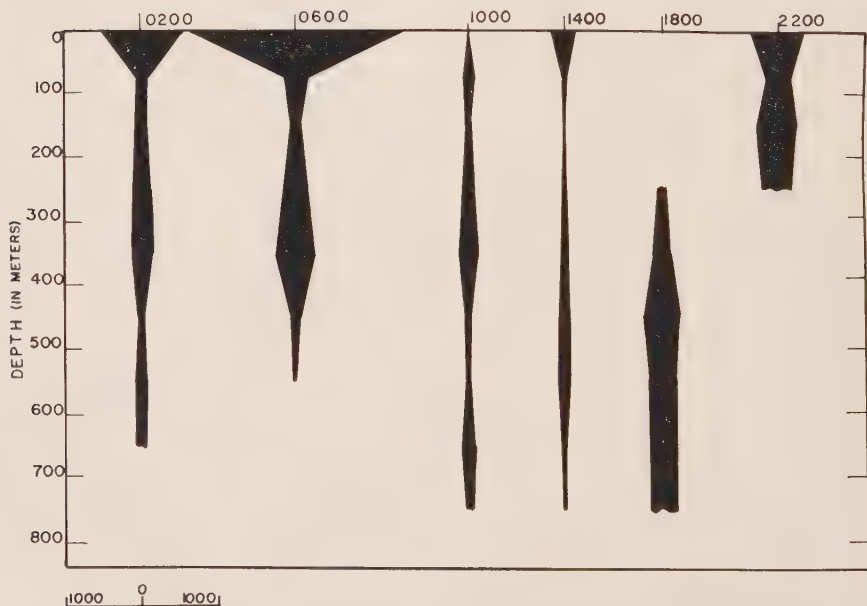


FIGURE 29. Vertical distribution of total chaetognaths at one Forty-Mile Station, showing diurnal migration.

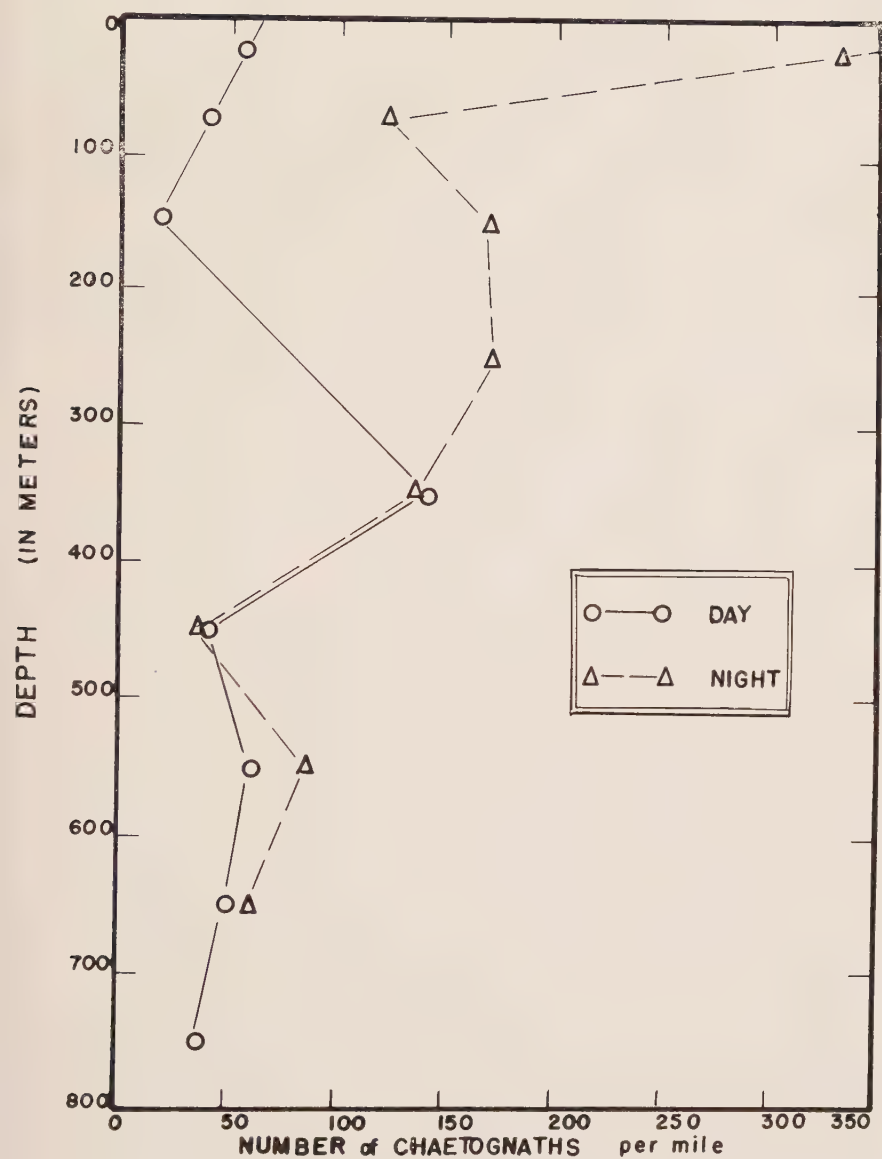


FIGURE 30. Vertical distribution of chaetognaths per mile tow at the Forty-Mile Station. Day (10-14 hr.), Night (22-02 hr.).

Siphonophores

Data on this group are based on the work of Roane (1953) and Moore (1953). At the Forty-Mile Station, the figures quoted as total siphonophores actually include only the eight commonest species. However, on a check of over three thousand siphonophores at the Ten-Mile Station, where the fauna is very similar, these eight species comprised over ninety-two per cent of all the siphonophores, so the figures may be taken as representative.

Diurnal migration is definite, although the range in general is not great (Fig. 36). The siphonophore population of the column down to 700 meters shows no diurnal change but a displacement of the concentration (Fig. 37) toward the surface, above 50 meters, occurs during the night.

The day number of siphonophores per cubic centimeter of plankton indicate a fairly steady decrease in importance from the euphotic zone downwards. This is shown in Fig. 38. At night, the relatively more extensive migration of the other groups leaves them with more or less uniform importance at all depths.

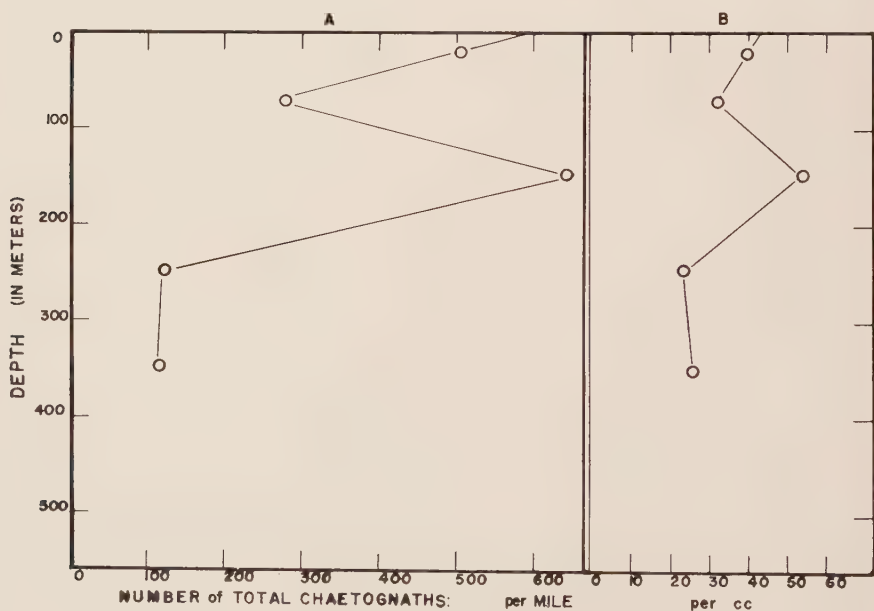


FIGURE 31. (A) Day vertical distribution of total chaetognaths per mile tow at the Ten-Mile Station. (B) Day vertical distribution of total chaetognaths per cubic centimeter of plankton at the Ten-Mile Station.

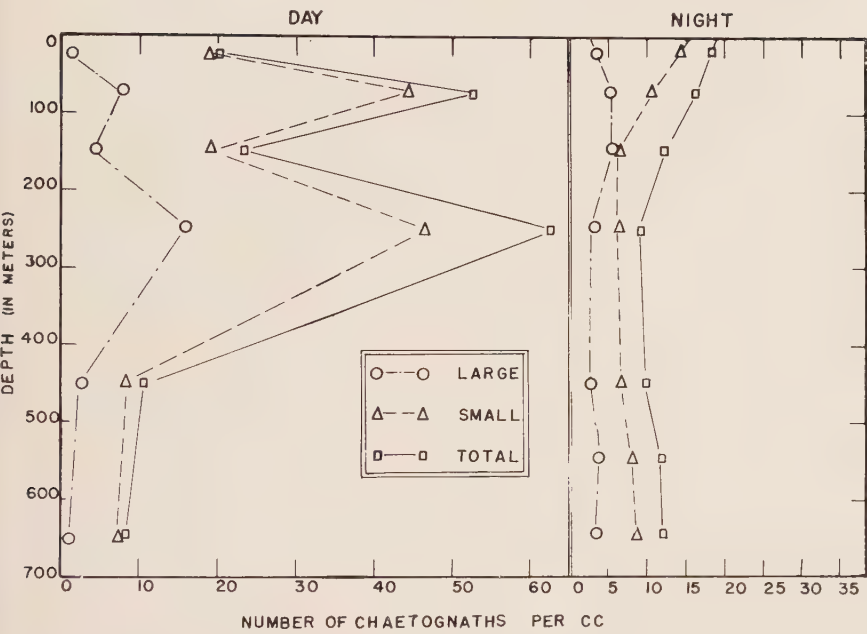


FIGURE 32. Vertical distribution of the number of chaetognaths, divided into large and small, per cubic centimeter of plankton at one Forty-Mile Station. Large includes *Sagitta hexaptera*, *S. lyra*, and *S. enflata*. Small include the remaining species. Day (10-14 hr.), Night (22-02 hr.).

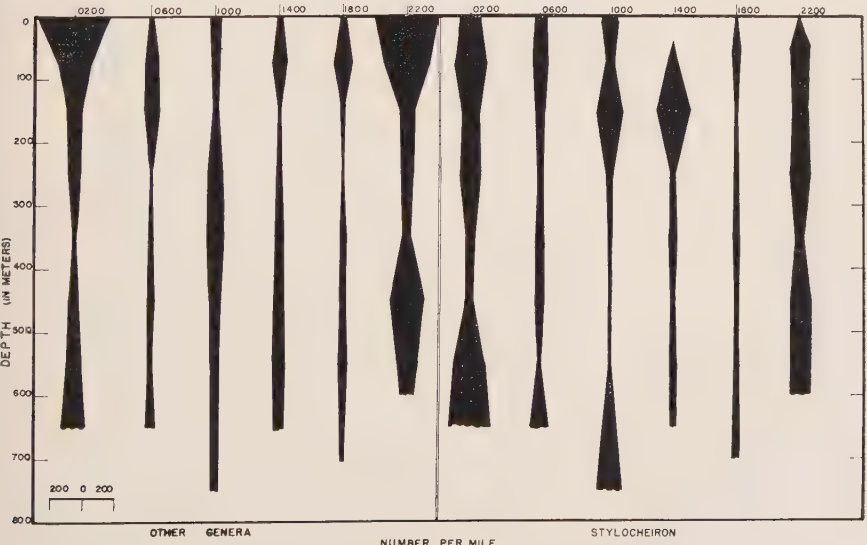


FIGURE 33. Vertical distribution of *Stylocheiron* spp. and of other genera at the Forty-Mile Station.

Fishes

In the course of life history studies, all fish, regardless of stage of development, have been separated from the hauls and counted. Several studies of particular groups have been published (N. Voss, 1954, J. Clancey, 1955, V. A. Legaspi, 1956, and G. L. Voss, 1953). From the total counts at the Forty-Mile Station (Fig. 39) it is clear that there is a very extensive diurnal migration among the fish. Since larval fish typically exhibit very little diurnal migration, the later stages of development must be involved. On the other hand, most of the more active fish are well able to escape capture, so these figures represent only a minimal estimate of the fish population. The increase in numbers in the euphotic zone at night is marked, the increase being about four to five fold, while for the whole column down to 650 meters it is over two fold (Fig. 40).

With this strong diurnal migration, the importance of fish in the

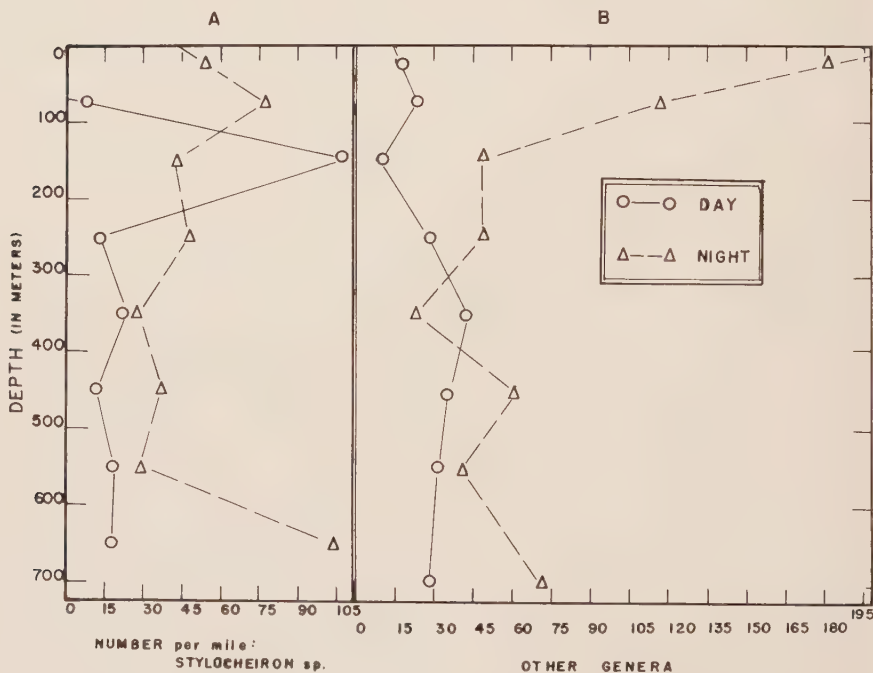


FIGURE 34. (A) Vertical distribution of *Stylocheiron* spp. per mile tow at the Forty-Mile Station. Day (12-16 hr.), Night (20-18 hr.). (B) Vertical distribution of other genera per mile tow at the Forty-Mile Station. Day (08-16 hr.), Night (20-04 hr.).

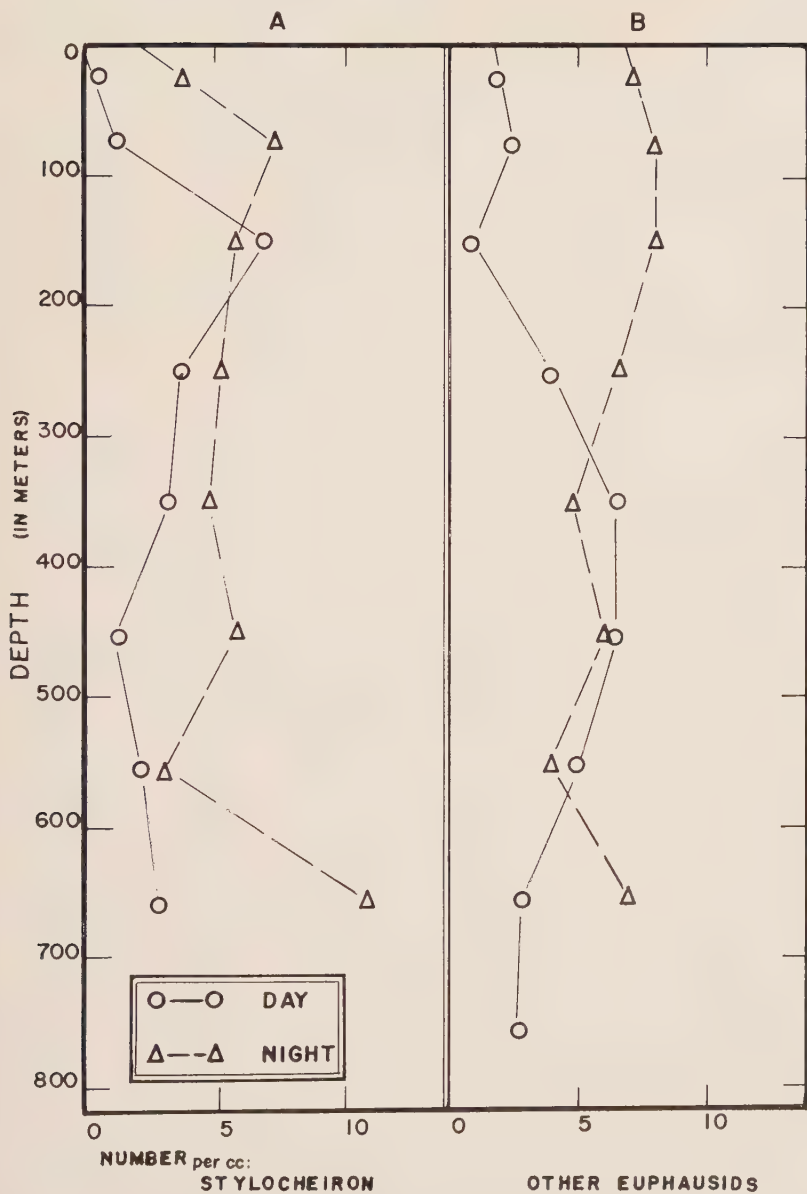


FIGURE 35. (A) Vertical distribution of *Stylocheiron* spp. per cubic centimeter of plankton at the Forty-Mile Station. Day (12-16 hr.), Night (20-08 hr.). (B) Vertical distribution of other genera of euphausiids per cubic centimeter of plankton at the Forty-Mile Station. Day (08-16 hr.), Night (20-04 hr.).

plankton population is greater at night at all depths except in the top 50 meters (Fig. 41) where it drops at night.

Cephalopods

These presumably are too active to be taken in the net hauls, except as larvae and even then in small numbers only. They were taken at the Forty-Mile Station on only one occasion in the day hauls (1200-1600 hours). At night they averaged about one for every two miles and were fairly uniformly distributed down to 700 meters. A considerable diurnal migration seems therefore to be indicated. These cephalopods have been separated by G. L. Voss and partially reported upon (Voss, 1955, 1956).

DRY WEIGHT AND VOLUME RELATION

An attempt has been made to correlate the zooplankton displacement volumes with their respective dry weights. An exact correlation cannot be obtained due to the variation in both number and size of the animals that comprise the different hauls. However, a rough esti-

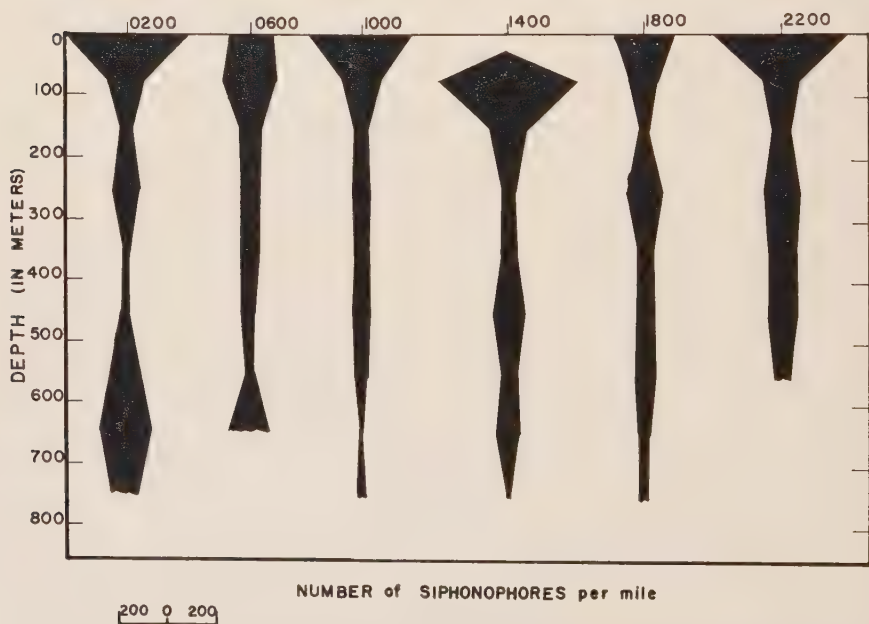


FIGURE 36. Vertical distribution of siphonophores at the Forty-Mile Station, showing diurnal migration.

mate of the dry weight of a typical plankton sample from this area of the Florida Current may be obtained using the curve of Figure 42. This curve was obtained by measuring the plankton displacement

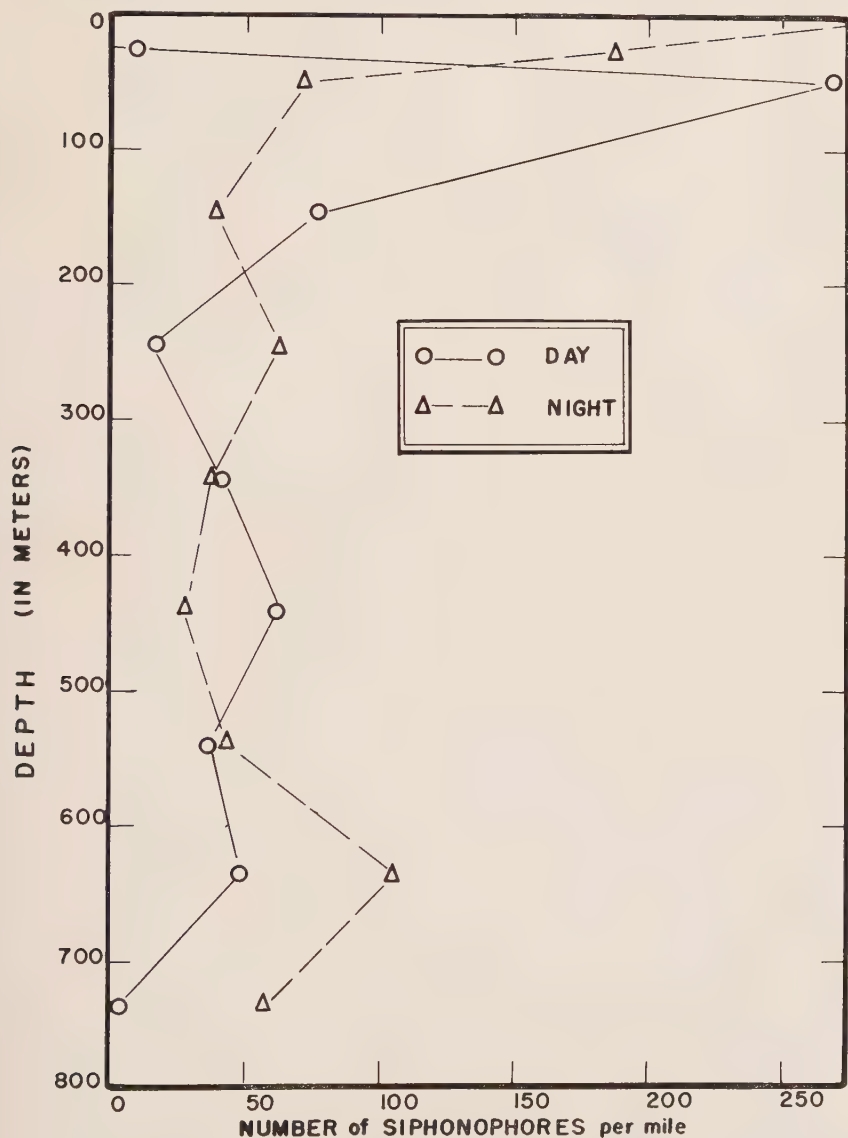


FIGURE 37. Vertical distribution of siphonophores per mile tow at the Forty-Mile Station. Day (12-16 hr.), Night (20-04 hr.).

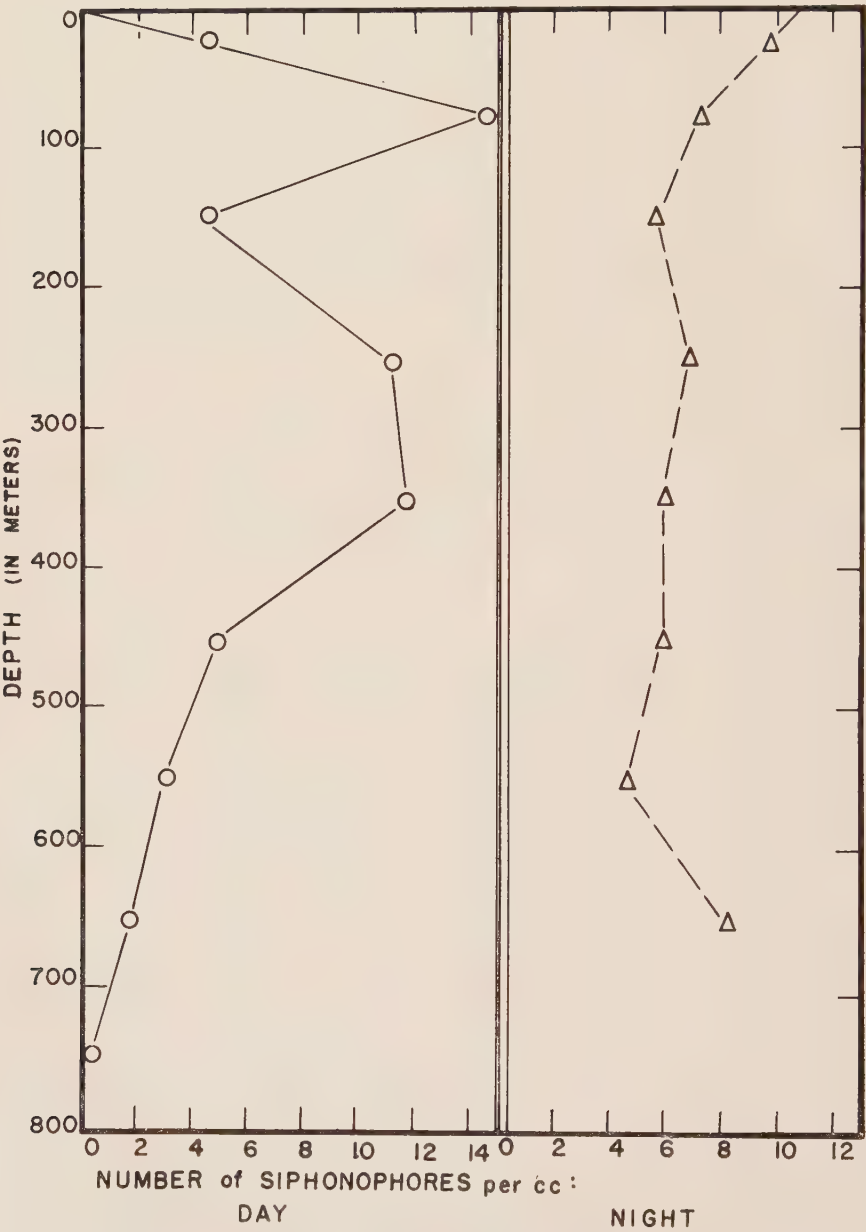


FIGURE 38. Vertical distribution of the number of siphonophores per cubic centimeter at the Forty-Mile Station. Day (12-16 hr.), Night (20-04 hr.).

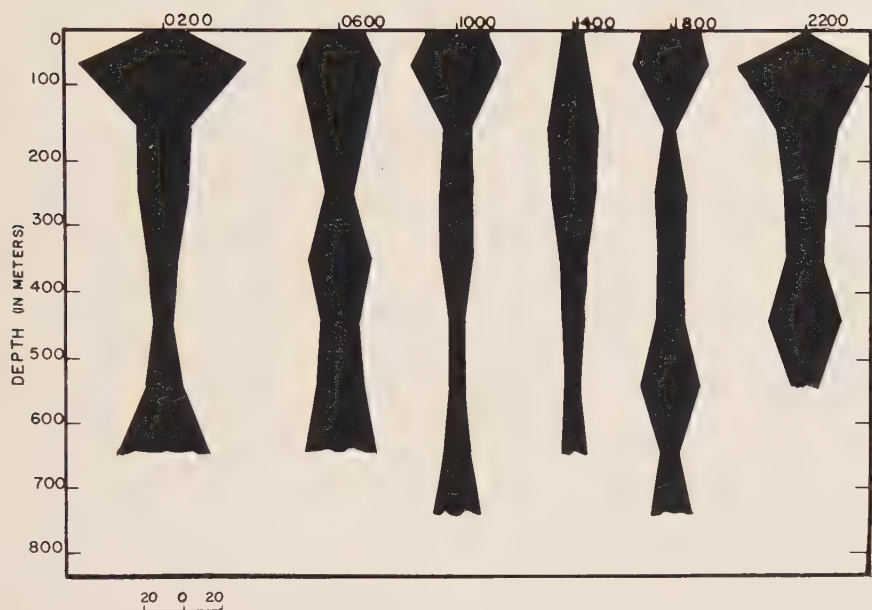


FIGURE 39. Vertical distribution of post-larval fish at the Forty-Mile Station.

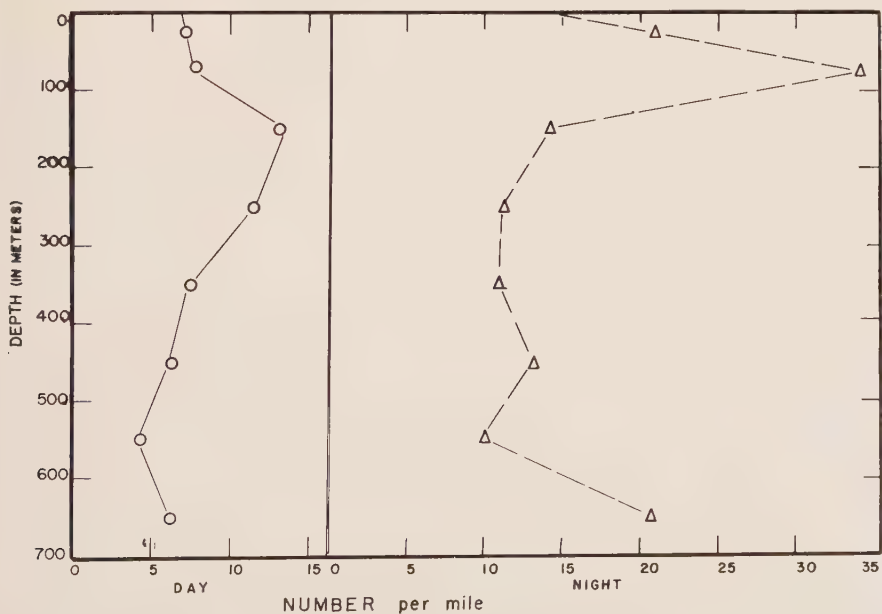


FIGURE 40. Vertical distribution of post-larval fish per mile tow at the Forty-Mile Station. Day (12-16 hr.), Night (20-08 hr.).

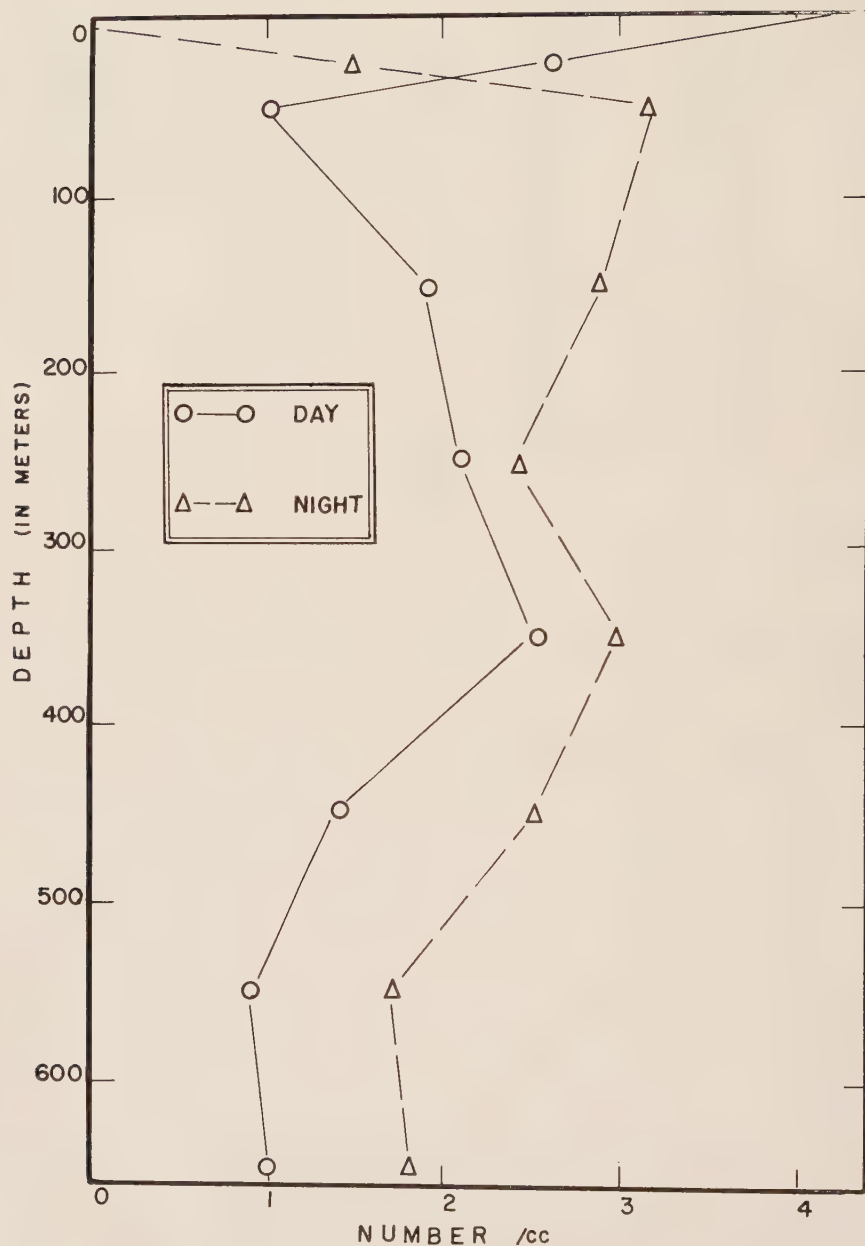


FIGURE 41. Vertical distribution of post-larval fish per cubic centimeter of plankton at the Forty-Mile Station. Day (12-16 hr.), Night (20-04 hr.).

volumes and dry weight for a series of typical bulk plankton samples. These samples were selected at random from both day and night hauls, as well as shallow and deep catches. A more accurate curve could be obtained by drying a great many more samples; however, at this stage of the investigation, it was not advisable since the plankton sample is completely destroyed for taxonomic studies by drying. The dry weight measurements do not include fish larvae or eggs as they were removed before drying the sample. The error introduced by this procedure is assumed to be negligible for dry weights, nevertheless they constitute a much larger fraction of the total volume and cannot be omitted from this measurement. Representative average volumes and dry weights were also determined for a series of copepods, euphausiids, chaetognaths, and siphonophores.

Figure 43 shows the accumulative total of the dry weights of these organisms for a day catch in relation to the total weight of the bulk plankton sample as determined by volume measurements. Figure 44 illustrates the accumulative total weights of the above species for night hauls. In both the day and night hauls, it is readily seen that the above mentioned groups comprise, on the average, 50 per cent or more of the total weight of a bulk plankton sample throughout the water column.

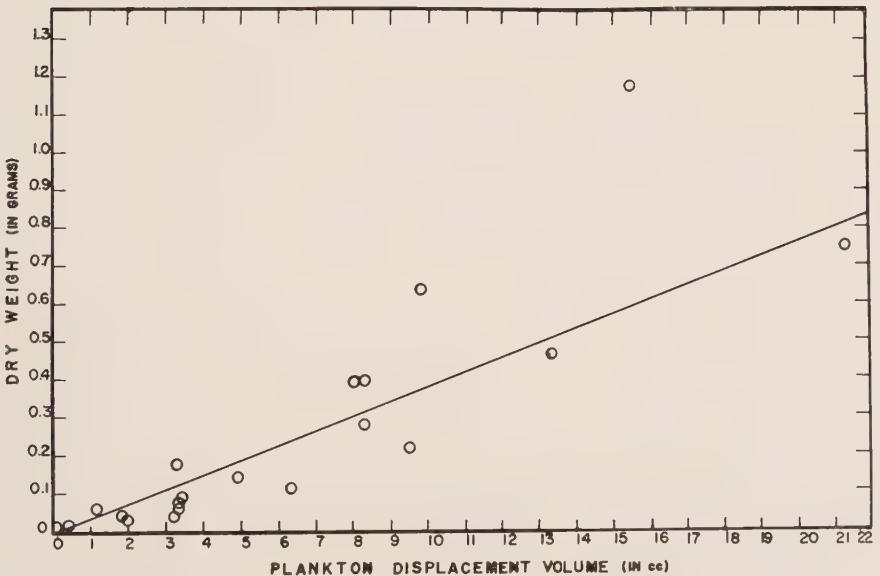


FIGURE 42. Dry weight of mixed plankton in relation to wet volume.

For day samples, the correlation drops off at a depth of approximately 500 meters. For night hauls the best correlation is obtained at depths below the euphotic zone or 100 meter level.

The above discrepancy in the correlations may be explained by the large variation in species that occurs in these two regions at the noted times. Table 2 shows the average dry weight and volumes for the individual groups considered. The average value for chaetognaths was determined on a basis of a number ratio between the large and small

TABLE 2
ZOOPLANKTON DRY WEIGHTS AND WET VOLUMES

Animal	Dry Wt. per Animal	Wet Vol. per Animal	Wt. per Unit Vol.
Euphausiids	1.753 mg.	27.2 μ l	0.0645
Chaetognaths	0.063	4.5	0.014
Siphonophores	0.126	42.9	0.00294
Copepods	0.024	1.3	0.01845
Copepods (Euphotic Zone Daytime)	0.0065		

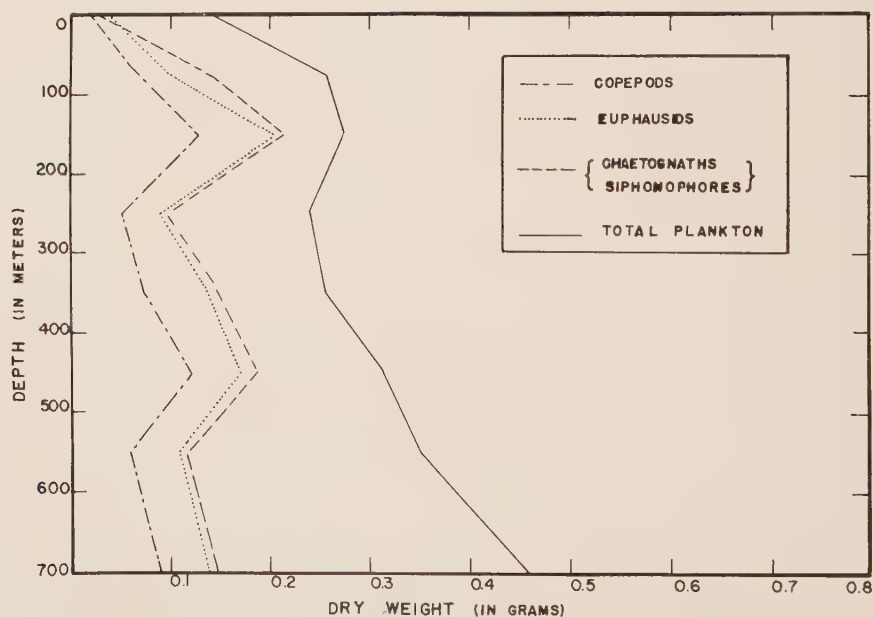


FIGURE 43. Accumulative totals of the dry weight of copepods, euphausiids, chaetognaths and siphonophores, as portions of the dry weight of total plankton in day hauls at the Forty-Mile Station.

animals found in a typical plankton sample. For the copepods, it was essential to calculate a separate weight for copepods in the euphotic zone for the day hours.

This was necessary since a plankton sample from the euphotic zone during the daylight hours contained a very large number of small copepods, *Calanus minor*, etc. If the average weight of the deeper copepods was used, the combined weight of the copepod population would exceed, in most cases, the total weight of the bulk plankton. Outside the euphotic zone, there is an average distribution between the large and small species.

In the euphotic zone for the night hauls (Fig. 44) the large difference between the accumulative dry weights of the four predominant organisms and the total dry weight can be partially attributed to the large number of animals that migrate into this zone at night, which were not considered in the accumulative dry weight curve. These include such plankton forms as pteropods and post larval fish. A discrepancy may also result from a higher percentage of the larger animals concentrating in the surface waters. For the lower depths during

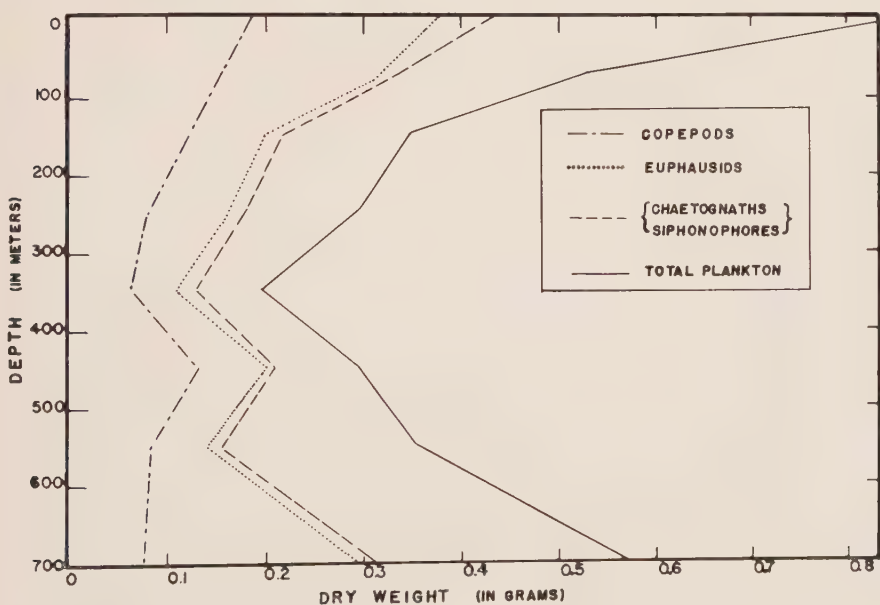


FIGURE 44. Accumulative totals of the dry weights of copepods, euphausiids, chaetognaths and siphonophores, as portions of the dry weight of total plankton in night hauls at the Forty-Mile Station.

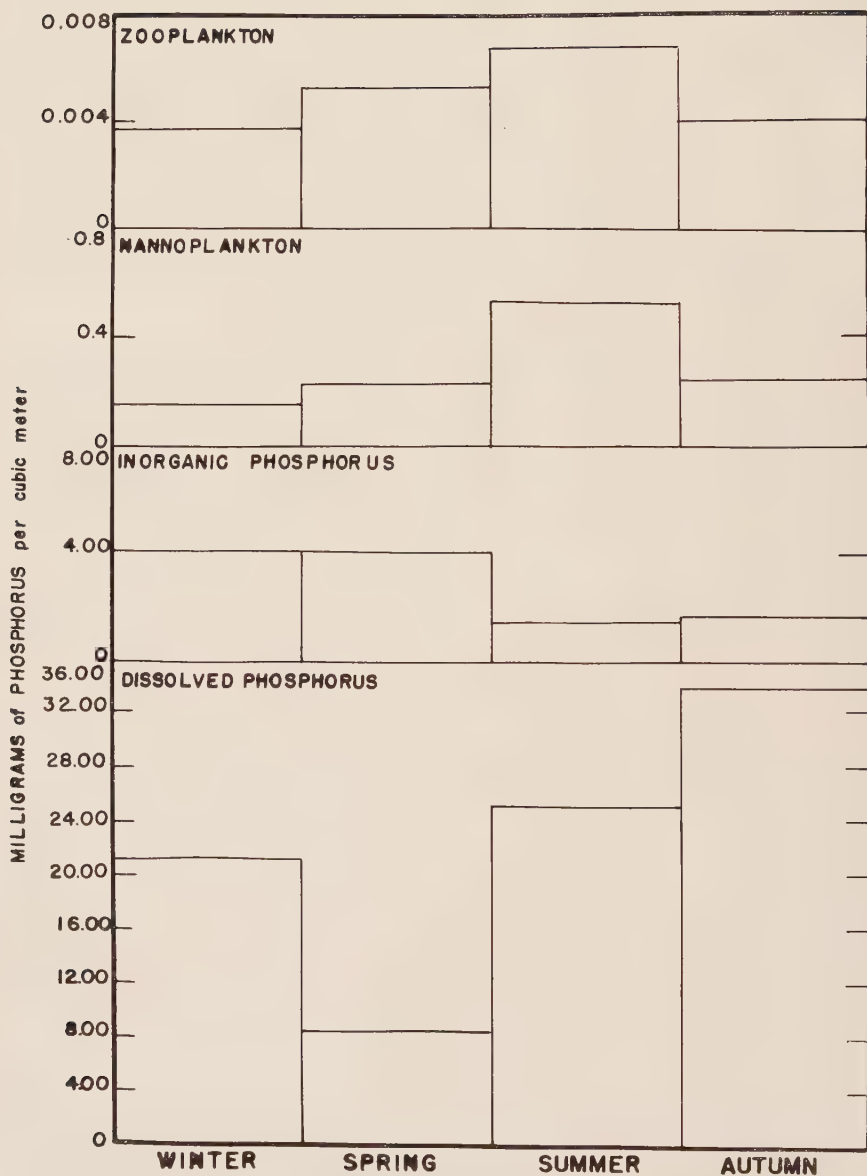


FIGURE 45. Diagram showing distribution of total phosphorus in euphotic zone at Forty-Mile Station.

the day, it is assumed that the larger animals, which concentrate at the surface at night, would migrate to the deeper waters so that the value used for their dry weights would be much too low. Even though these graphs are rather crude due to insufficient data, they can still be successfully used to obtain a rough estimate of the percentage composition of a bulk plankton sample from the Florida Current in this immediate area.

DISCUSSION

The Florida Current is a fast moving body of water whose composition is somewhat intermediate between the open waters of the Atlantic Ocean and the more sheltered coastal waters. It is only partially cut off from the Atlantic Ocean on the eastern edge by the Bahama Banks and is bound on the western edge by the Florida Coast. The waters forming this current originate, as indicated by salinity measurements, mainly from waters flowing through the Yucatan Channel. At various times during the year, the more shallow western edge along the Florida Coast is somewhat modified by intrusion of waters from the Gulf of Mexico.

Any marine population is controlled quantitatively by certain processes, the rates of which are determined by a complicated series of environmental factors. These factors exert great influence on the physiology and physical distributions of the planktonic organisms. The production of the zooplankton population may be modified by temperature and the available food supply. Under oceanic conditions it is doubtful if either oxygen or salinity vary significantly. The standing crop reflects the balance between rates of productivity and predation. Therefore, in the present study a distinction was drawn between the major herbivores—copepods and euphausiids; and the major carnivores—siphonophores, chaetognaths, and fishes. Unfortunately, the last of these were inadequately sampled. Phytoplankton production depends on illumination, temperature and nutrients. The standing crop reflects the balance between productivity and grazing. The general procedure here has been to consider the planktonic and chemical conditions in two units, as euphotic and deep zones.

The physical composition of the planktonic organisms in the Florida Current is mainly nannoplankton and zooplankton. The nannoplankton comprise the bulk of the phytoplankton present, the net-caught phytoplankton being of little value in the estimation of productivity, since they are far outnumbered by the quantity of nanno-

plankton present, the weight ratio being about 1000:1. The herbivore population is well represented by the copepods which comprise approximately one third of the zooplankton. The chaetognaths represent the carnivores which form the second major division of the zooplankton. Together with the euphausiids and siphonophores they form the major groups of zooplankton found in this area. However, there are other minor groups.

Present data on the nannoplankton indicate that between 85 and 90 per cent of these organisms are found in the euphotic zone. Below the compensation depth, the quantity of nannoplankton was found to diminish rapidly. The greatest concentration appeared during the late summer months and in the upper 35 meters where the light intensity is high. The dissolved nitrate values in the immediate surface area (10 meters) were not large, being less than five microgram-atoms per liter. For the remaining portion of the euphotic zone, the nitrate values ranged from 5 to 10 microgram-atoms per liter. The inorganic dissolved phosphate values were even lower in this zone and, during the nannoplankton bloom, the values were 0.1 microgram-atoms or less. The N:P ratio for the waters of the euphotic zone were very high, the average value being around 60:1. Both nitrate and phosphate were low at all times in the euphotic zone, but of the two, phosphate appears likely to be the limiting factor. Salinity and temperature effects on the nannoplankton are not known since the identification and physiology of these organisms has been little investigated. The extent to which nannoplankton utilize organic nutrients is not known. Some forms at least can utilize amino acids. It is permissible to speculate that, under tropical conditions, much decaying organic matter may be removed from solution by nannoplankton before it has had time to break down into the simple salts which can be utilized by diatoms. The latter might, thereby, be largely eliminated from the phytoplankton population in those regions where conditions particularly favor the nannoplankton.

All zooplankton showed diurnal migration, with considerable variation occurring among the species present. This greatly affected the general constitution of the plankton samples. A marked increase occurred in the plankton volumes of the surface waters during the night, while at the lower levels, as deep as they were sampled, the total volume remained rather constant.

The copepods performed a smaller diurnal migration than some other groups. Although there was an increase in the number of copepods during the night at the surface, the relative per cent of the total

plankton dropped to approximately one third of the day value. It should be noted that during the day, the copepods found in the surface layers were generally very small and the larger animals migrated to this area at night. Thus the copepods in the euphotic zone were much more important constituents of the plankton during the day. By the same token, in the deeper layers they were more important at night.

Pteropods and chaetognaths showed strong diurnal migration. In the euphotic zone the pteropods at night increased about 19 fold and the chaetognaths 5 fold. These observations were based on one station only and may need revision as more data becomes available. Euphausiids also showed a marked diurnal migration with an increase of around 7 fold in the euphotic zone at night. Siphonophores revealed a definite diurnal migration although, in general, the range was not as large as in the pteropods and chaetognaths. Thus the siphonophores assumed at all depths an importance which depended on the extent of the migration of the other zooplankton.

A small seasonal variation has been observed for the zooplankton in this area of the Florida Current. The maximum increase, which occurs from March through June, was of the order of three times the average for the remainder of the year. Small seasonal changes of the zooplankton have been reported for the Bermuda area (Moore, 1949) and for the Ten-Mile Station off the Miami coast (Miller, *et al.*, 1953). However, in both of these areas, it is not definitely known if the changes are due to production or to the continual fluctuations in the water masses. Smith, *et al.* (1950) have shown that for the organisms of Biscayne Bay, a two fold increase occurs in July and in December-January periods. Fish (1956) reports a seasonal variation for the zooplankton of the North Sargasso Sea, with the maximum abundance occurring for a period from April through June. At the height of this maximum, the increase is approximately thirty fold over the rest of the year. Minor fluctuations occur in the cycle until a minimum is reached during the November-December period. In comparing the abundance of zooplankton in the Sargasso Sea with that of the Labrador Sea, he found the latter to be approximately three times as rich; the yearly average number of organisms per cubic meter being 239 for the Sargasso Sea and 690 in the Labrador area. The yearly average number of plankton calculated for this area of the Florida Current is 12 per cubic meter. The present work utilized a considerably coarser net than was used by Fish and such smaller forms as copepod nauplii were undoubtedly missed. On the other hand, he used a smaller net, for which the

escape factor, in the more active forms, would be greater. The 20 fold difference between Fish's values and those of the Florida Current cannot be attributed entirely to differences in collecting methods. However, plankton volumes reported by Jespersen (1923) for shallow hauls show that the region east of Florida contains about one third of the plankton volumes found in the area covered by the Fish survey. Plankton volumes given by Moore (1949) for ocean waters near Bermuda, caught with identical nets, were considerably greater than the values found for Florida Current waters in the present study.

Nitrogen and phosphorus analyses were carried out on dried zooplankton samples of 10-30 milligram fractions. A series of random samples yielded an average nitrogen content of 6.84 per cent of the dry weight. Phosphorus values averaged 0.65 per cent, thereby giving a N:P ratio of 10.6:1. Harris and Riley (1956) obtained for the zooplankton in Long Island Sound, average nitrogen and phosphorus values of 8.9 per cent and 0.82 per cent, respectively, and an N:P ratio of 10.9:1.

Figure 45 shows the seasonal variations of the nanoplankton and zooplankton expressed as phosphorus and of dissolved inorganic and organic phosphates. It is readily seen that a large percentage of the total phosphorus in a given water mass is in the form of dissolved organic phosphorus, the value being over 90 per cent for the summer and autumn periods. This large value follows the summer nanoplankton bloom. The dissolved inorganic phosphorus attains its highest percentage of the total phosphorus during the winter and spring seasons. The phosphorus fixed in plankton organisms, as expected, attained its greatest values in the spring and summer months. However, at all times phosphorus was present in largest concentration in the dissolved organic form.

Yearly averages of dry weights for the standing crop of plankton in the Florida Current have been computed for the euphotic zone. Zooplankton dry weights were found to be 0.45 milligrams per cubic meter. This, however, is probably, as mentioned previously, an underestimate. Nevertheless, this value is much smaller than those reported by Riley (1949) for the Gulf Stream and Sargasso Sea, namely, 148 milligrams for the former and 10 to 87 milligrams for the latter. Nanoplankton dry weight was found to be 46.1 milligrams, a hundred fold increase over the zooplankton. It must be remembered that the nanoplankton represents not only the small phytoplankton but also non-photosynthetic protista and particulate matter. It is believed that

the particulate matter comprises only a small percentage of the total dry weight, since the concentration decreases so rapidly below the euphotic zone. Debris from zooplankton would be expected to concentrate deeper, that is at or below the maximum concentration of the zooplankton. Matter of terraqueous origin can reach these waters to any extent only when airborne. However, identification of the nature of this particulate phosphorus will require further study.

There is a considerable seasonal change in the total phosphorus content of the euphotic zone and the waters slightly deeper. Winter mixing cannot enrich these surface waters as it does in colder regions. The seasonal differences might reflect changes in the water mass flowing through the Florida Straits although other characteristics of the water do not confirm this. We know little at present about the vertical transfer of organic and inorganic phosphorus by diurnal migrating plankton, but this may well prove to be significant in quantity. It may, at least, be significant that the maximum total phosphorus content of the euphotic zone is in the summer and winter, following closely the early summer maximum in the zooplankton populations.

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FLORIDA STRAITS TRANSPORTS, 1952-1956¹

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Through the generosity of the Western Union Telegraph Company it has been possible to make continuous measurements over weekends of the potential difference between Key West and Havana, across the Florida Straits, since August 1952. The records are obtained at the Key West end of the cable by the Western Union cable engineer, Mr. P. J. Moore, to whom we are very much indebted for volunteering to look after the recording equipment for these years. A preliminary discussion, in detail, of the first year's data (1952-1953) has been published by Wertheim (1954). There are now available nearly four years' data, none of which has been published in tabular form. In order to make these data readily available to oceanographers at large, it has been prepared in summary form in the accompanying table (Table 1).

TABLE 1
 24-HOUR AVERAGES OF FLORIDA STRAITS TRANSPORTS
 IN MILLIONS OF CUBIC METERS PER SECOND.

1952			1952			1953			1953		
Aug.	3	30.3	Nov.	1	19.9		11	34.3		29	23.5
	9	26.8		2	22.3		17	30.4			
	10	27.4		4	23.1		18	29.7	Apr.	3	25.3
	16	28.9		8	21.9					4	26.9
	17	26.3		9	21.9	Feb.	1	28.7		5	24.8
	23	19.6		11	26.5		7	32.7		11	26.0
	24	18.3					8	34.6		12	28.8
	31	21.9	Dec.	6	15.8		12	36.6		18	35.0
				7	14.6		14	36.3		19	37.2
Sept.	7	19.1		13	20.5		15	37.5		25	39.0
	13	19.1		14	23.3		21	33.1		26	38.3
	14	18.6		20	27.6		22	31.8			
	27	21.2		21	27.9		23	33.4	May	2	36.9
	28	20.0		25	31.0		28	31.1		3	36.6
				27	30.3					9	36.4
Oct.	4	21.9		28	30.9	Mar.	1	28.4		10	35.6
	5	20.1					7	24.1		16	32.8
	11	23.3	1953				8	21.6		17	34.1
	12	23.7					14	23.0		23	33.4
	18	24.7	Jan.	1	38.0		15	22.0		24	34.1
	19	24.5		3	36.8		21	24.7	May	30	31.2
	25	17.4	Jan.	4	34.7		22	23.1		31	32.1
	26	20.2		10	35.6		28	21.9			

¹Contribution No. 845 of the Woods Hole Oceanographic Institution; this work was done under contract with the Office of Naval Research: N6onr-27701.

TABLE 1—Continued
24-HOUR AVERAGES OF FLORIDA STRAITS TRANSPORTS
IN MILLIONS OF CUBIC METERS PER SECOND.

1953			1953			1954			1955				
June	6	32.9	Dec.	5	23.8	July	17	23.8			24	25.5	
	7	34.0		6	23.3		18	23.2			30	23.3	
	13	27.5		12	26.1		24	27.1					
	14	26.8		13	27.4		25	27.1	May	1	20.2		
	20	26.3		19	22.0		31	29.4					
	21	26.4		20	23.0				CABLE BREAK				
	27	21.5		25	24.8	Aug.	1	30.7					
	28	22.3		26	24.3					Nov.	12	22.5	
			27	23.3	Nov.	28	24.8	19	24.1				
						29	24.8	26	33.4				
July	4	24.7	1954				Dec.	4	24.3	Dec.	3	32.4	
	5	24.5						5	23.8		10	29.2	
	11	27.3						11	24.6		17	30.6	
	12	26.8		Jan.	2	21.8	12	24.8	24	29.7			
	25	24.8			3	24.8	18	29.7					
	26	25.3			9	20.5	19	31.0					
Aug.	1	22.8	10	22.5	1955	19	27.4	1956					
	2	23.8	16	22.3		25	27.4						
	8	23.3	17	24.1		26	27.9						
	9	24.1	Feb.	6		26.6				Jan.	8*	25.7	
	16	23.8		7		27.1				Jan.	14*	22.8	
	30	23.8		13		24.1				21	24.0		
				20		21.2	Jan.		1	26.9	28	27.8	
				21		20.7			2	27.1	29	32.3	
Sept.	5	25.9	Mar.	7	22.0	8		21.4	Feb.	4	25.8		
	6	23.0		14	26.6	9		21.7		5	23.8		
	7	23.0						15		18.7	11	22.7	
	12	16.6		Apr.	3	24.3		Jan.		16	19.6	12	25.8
	13	18.2			4	24.6	22			16.1	18	22.4	
	19	22.5			10	27.6	23			17.4	26	28.9	
	20	23.6	11		23.5	29	15.3		Mar.	10	23.0		
	26	19.7	18		24.3	30	15.4			11	27.0		
	27	22.0	24	20.7	Feb.	5	17.8	17		23.7			
	Oct.	4	17.7	May		25	20.7	6		20.5	18	21.7	
		10	17.7			1	20.0	12		22.5	24	15.3	
11		16.9	2			21.2	13	20.0	25	16.5			
12		16.4	8		21.5	Mar.	5	26.1	31	18.6			
17		16.6	9		23.8		6	27.2	Apr.	1	18.7		
18		15.6	15		31.2		12	27.9		7	24.1		
24		16.6	16		30.7		13	29.2		8	22.6		
31		20.5	22		27.6		19	30.7		14	21.8		
Nov.		1	22.0		23	25.3	20	30.4		15	22.5		
		7	19.7		30	27.9	26	33.5	22	26.9			
		8	20.0					27	33.8	29	30.7		
	14	17.7	June	5	26.1								
	15	15.9		6	25.1	Apr.	2	29.9	May	5	32.7		
	21	25.6		12	19.7		9	30.7		6	32.2		
	28	23.6		13	21.0		10	29.2		13	26.4		
	29	24.1		20	26.4		16	31.1		19	24.8		
				26	27.4		17	29.2		26	24.0		
				27	27.6	23	27.2	27	23.0				

The figures presented in the table are the 24-hour averages of water transport (in millions of cubic meters per second) through the Florida Straits between Key West and Havana. The averages are always taken from midnight to midnight, local time (75°W meridian), except in two cases marked with an asterisk, where the average is taken from noon to noon of the following day. These figures are computed by multiplying the 24-hour average voltage (in volts) by the factor 25.6, to obtain the transport in millions of cubic meters per second. Wertheim (1954) has emphasized the ambiguities which enter in passing from measured voltage to computed transport; if, in the future, there is reason to doubt the validity of the parameters chosen to obtain the factor 25.6, the tabulated values can always be divided by this factor to recover the original average measured potential difference in volts (for example, the actual average potential difference measured on November 21, 1953 was 1.00 volts).

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SOME DIGENETIC TREMATODES OF MARINE FISHES OF THE BAHAMA ISLANDS¹

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ABSTRACT

During late February and early March, 1952, 25 fish of 17 species were collected from the areas of Nassau and Eleuthera, Bahamas, and examined for digenetic trematodes. Fifteen of the species, including 21 individuals, harbored digenetic trematodes. Twenty-three species of trematodes were identified, 16 new host records were established, and a new record for the Atlantic Ocean of a species described from the Pacific Coast of California was cited.

A close relationship between the trematode faunas of the Dry Tortugas, Florida, and the Bahama Islands was found; a much closer relationship than occurs between the faunas of the Dry Tortugas and Bermuda or the faunas of the Bahama Islands and Bermuda.

INTRODUCTION

Through a cooperative arrangement between the Department of Oceanography of the A & M College of Texas and the U. S. Fish and Wildlife Service, the writer had the opportunity to make a cruise, in early 1952, aboard the Motor Vessel ALASKA to the Bahama Islands. While on this cruise a number of fish were examined for digenetic trematodes. It was found that the Bahama Islands supports an unusually rich trematode fauna.

Prior to this study no records of collections of trematodes from the Bahama Islands has appeared in the literature. Vigueras (1940 and 1940a) described five new species from the vicinity of Puerto Rico. Linton (1907a) studied the digenetic trematodes of Bermuda. Hanson (1950) reported on a collection made there by Dr. F. D. Barker and reviewed Linton's work. Linton (1907, 1910, 1911) did the pioneer research on the trematodes of the Dry Tortugas, Florida. Manter, in a series of papers from 1930 to 1949, reported on his studies of the Digenea of the Dry Tortugas.

Grateful acknowledgment and sincere appreciation is extended to Dr. Hurst Shoemaker, Gulf Coast Research Laboratory and the University of Illinois, who helped the author to select the correct names of fish hosts as did Dr. Gordon Gunter, Director of the Gulf Coast Research Laboratory; to Dr. Sewell H. Hopkins, Department of Biology, the A & M College of Texas, who directed the author's research and gave valuable advice on the organization of this paper; and to

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Dr. J. G. Mackin, Texas A & M Research Foundation, who read the manuscript and offered suggestions to the author.

All collections were from Nassau, Bahamas, unless specified otherwise. Throughout the paper new host records are indicated by an asterisk. The fishes were identified by the use of Breder's *Field Book of Marine Fishes of the Atlantic Coast* (Breder, 1948).

TAXONOMIC LIST

Family BUCEPHALIDAE

1. *Rhipidocotyle capitatum* (Linton, 1940) Manter, 1947

Host: **Holocentrus ascensionis* (Osbeck), squirrel fish, in 1 of 3

Other Hosts: *Auxis thazard* (Lacepede), frigate mackerel; *Euthynnus alleteratus* (Rafinesque), little tuna

Other Localities: Woods Hole, Massachusetts; Atlantic Ocean near Miami, Florida (unpublished records); Grand Isle, Louisiana (unpublished records)

This species may be synonymous with *R. nagaty* Manter, 1940, in which case *R. capitatum* would have priority. Manter (personal correspondence) thinks both species should be recognized until further comparison of the two species can be made.

2. *Rhipidocotyle barracudae* Manter, 1940

Host: *Sphyræna barracuda* (Walbaum), great barracuda, in 1 of 2

Locality: Spanish Wells, Bahamas

This species has been recorded only from the Dry Tortugas, Florida, but has also been found by the author in the western Gulf off the coast of Mexico (unpublished data).

Family LEPOCREADIIDAE

3. *Lepocreadium trulla* (Linton, 1907) Linton, 1910

Host: *Calamus calamus* (Cuvier and Valenciennes), saucer-eye porgy in 1 of 1

Other Hosts: *Ocyurus chrysurus* (Bloch), yellowtail; **Lutjanus aya* (Bloch), red snapper (unpublished data)

Other Localities: Dry Tortugas, Florida; Bermuda; Grand Isle, Louisiana (unpublished data)

Linton lists this host (1910) suggesting it was possibly an accidental infection. This collection, of thirteen mature specimens, suggests that *Calamus* is a normal host of *Lepocreadium trulla*.

4. *Multitestis rotundum* Sparks, 1954

Host: **Calamus calamus* (Cuvier and Valenciennes), saucer-eye porgy,

in 1 of 1

Other Host: *Archosargus probatocephalus* (Walbaum), sheepshead

Other Locality: Port Aransas, Texas

A single specimen of what appears to be *M. rotundum* was found in *C. calamus*, which belongs to the same family as the type host.

5. *Lepidapedon levenseni* (Linton, 1907) Manter, 1947

Host: **Holocentrus ascensionis* (Osbeck), squirrel fish, in 1 of 3

Other Hosts: Several species of *Epinephelus*

Other Localities: Dry Tortugas, Florida; Bermuda

Family OPECOELIDAE

6. *Pseudopecoeloides gracilis* Manter, 1947

Host: *Trachurops crumenophthalmus* (Bloch), goggle-eyed scad, in 1 of 1

Other Locality: Dry Tortugas, Florida

7. *Neopecoelus scorpaenae* Manter, 1947

Host: **Scorpaena plumieri* Bloch, West Indian scorpion fish, in 1 of 1

Other Hosts: *Scorpaena grandicornis* Cuvier and Valenciennes, lionfish; *S. braziliensis* Cuvier and Valenciennes, Brazilian scorpion fish

Other Locality: Dry Tortugas, Florida

8. *Neopecoelus holocentri* Manter, 1947

Host: **Holocentrus ascensionis* (Osbeck), squirrel fish, in 1 of 3

Other Host: *Holocentrus coruseus* (Poey), squirrel fish

Other Locality: Dry Tortugas, Florida

9. *Hamacreadium mutabile* Linton, 1910

Hosts: *Lutjanus analis* (Cuvier and Valenciennes), muttonfish, in 1 of 1; *Ocyurus chrysurus* (Bloch), yellowtail, in 1 of 1

Other Hosts: Nine species of fish, mostly of the genus *Lutjanus*

Other Localities: Japanese Pacific; Tropical American Pacific; Red Sea; Dry Tortugas, Florida

10. *Helicometra execta* Linton, 1910

Host: **Malacanthus plumieri* Bloch, sandfish, in 1 of 4

Other Hosts: 11 species representing several families

Other Locality: Dry Tortugas, Florida

It is unusual for a marine digenetic trematode to be found in more than one family of fish, usually being confined to one species or to several closely related species in the same genus or closely related genera. *Helicometra execta* is now known to be capable of parasitizing a dozen species of widely divergent families; it is surprising that its

known geographic range is so limited, being known only from Dry Tortugas, Florida and the Bahama Islands. Some of the other species of the genus are not so restricted in distribution. *H. fasciata*, for example, has been collected from Naples, Italy, and Tasmania.

11. *Stenopera equilata* Manter, 1933

Host: *Holocentrus ascensionis* (Osbeck), squirrel fish, in 3 of 3

Localities: Nassau, Bahamas, and Eleuthera

Other Locality: Dry Tortugas, Florida

12. *Helicometrina nimia* Linton, 1910.

Hosts: *Calamus calamus* (Cuvier and Valenciennes), saucer-eye porgy, in 1 of 1; **Lutjanus analis* (Cuvier and Valenciennes), muttonfish, in 1 of 1; **Cephalopholis fulvus* (Linnaeus), coney, in 1 of 1; *Scorpaena plumieri* Bloch, scorpion fish in 1 of 1; and **Malacanthus plumieri* (Bloch), sandfish, in 1 of 4

Other Hosts: 12 species including cardinal fish, porgies, snappers, and scorpion fish

Other Localities: Dry Tortugas, Florida; Mexican Pacific

The specimens collected from *Malacanthus plumieri* were small and almost all immature. They were not identified as *Helicometrina parva* Manter, however, because they possessed the nine testes typical of *H. nimia* rather than five testes as in *H. parva*.

13. *Helicometrina elongata* Noble and Park, 1937

Host: **Ancylopussetta quadrocellata* Gill, ocellated flounder, in 1 of 1

Other Hosts: *Sicygaster meandrica* (Girard), suckfish; *Clinocottus analis australis* Hubbs; *Gibbonsia elegans* (Cooper); *G. meti* Hubbs

Other Locality: California

In addition to being a new host record, this is the first time this species has been reported from the Atlantic Ocean.

Family ACANTHOCOLPIDAE

14. *Stephanostomum casum* (Linton, 1910) MacFarlane, 1936

Host: **Malacanthus plumieri* Bloch, sandfish, in 1 of 4

Other Hosts: Family Lutjanidae, including 5 species of *Lutjanus* and *Ocyurus chrysurus* (Bloch), yellowtail

Other Localities: Dry Tortugas, Florida; Galapagos Islands; British Columbia

Manter (1947) doubts MacFarlane's record of this species from British Columbia.

15. *Stephanostomum microstephanum* Manter, 1934

Host: **Holocentrus ascensionis* (Osbeck), squirrel fish, in 1 of 3

Other Host: *Epinephelus niveatus* (Cuvier and Valenciennes), snowy grouper

Locality: Eleuthera, Bahamas

Other Locality: Dry Tortugas, Florida

Family FELLODISTOMATIDAE

16. *Tergestia pectinata* (Linton, 1905) Manter, 1940

Host: *Trachurops crumenophthalmas* (Bloch), goggle-eyed scad, in 1 of 1

Other Hosts: Several fish from Families Carangidae and Sciaenidae

Other Localities: Woods Hole, Massachusetts; Beaufort, North Carolina; Dry Tortugas, Florida

Tergestia pectinata was described by Linton (1905) as *Distomum pectinatum*. Linton (1910) placed it in a new genus as *Theledera pectinata*. Both Manter and Hopkins discovered in 1940 that Linton's *Theledera* was synonymous with *Tergestia*. Manter's paper proposing the change appeared in March, 1940; Hopkins' proposal for the same change was published in July, 1940. Linton records this species from Woods Hole but Manter (1940, 1947) doubts the validity of this record, believing that *T. laticollis* was the species found at Woods Hole.

Family HAPLOSPLANCHNIDAE

17. *Haploplanchnus adacutus* Manter, 1937

Hosts: **Scarus croicensis* Bloch, Bahama parrotfish, in 1 of 1

Other Hosts: *Abudefduf marginatus* (Linnaeus), sergeant major; *Hali-choeres bivittatus* (Bloch), slippery dick; *H. maculipinna* (Muller and Troschel), slippery dick

Scarus croicensis represents a third family of fishes from which *H. adacutus* has been reported. It should be noted, however, that the three families are closely related. This relation is particularly close in the Wrasses, Family Labridae, and the parrot fishes of the family Scaridae; the two families making up the Suborder Pharyngognathi.

Family MONORCHIDAE

An unidentified monorchid was collected from *Lutjanus analis*.

18. *Genolopa ampullacea* Linton, 1910

Host: *Haemulon sciurus* (Shaw), blue-striped grunt, in 1 of 1

Other Hosts: Numerous species of Family Haemulidae; *Synodus foetens* (Linnaeus), lizard fish

Other Localities: Dry Tortugas, Florida; Bermuda

The author doubted for some time that the forms considered here

belonged to this species because of the presence of a long esophagus in these specimens rather than a short esophagus as stated in Linton's description and an elongate body shape in all my specimens in contrast to the urn shape described by Linton. However, Manter (1942) describes the body shape as varying from circular to elongate and gives measurements of the esophagus within the limits of which my specimens fall. *Synodus foetens*, lizard fish (Manter, 1947) is the only reported host of this species not belonging to the family Haemulidae; this was probably an accidental infection since it occurred in a single case and in an unrelated host.

Family CRYPTOgonimidae

19. *Siphodera vinaledwardsii* (Linton, 1899) Linton, 1910

Host: Ocyurus chrysurus (Bloch), yellowtail, in 1 of 1

Other Hosts: Opsanus tau (Linnaeus), toadfish; *Orthopristis chrysopterus* (Linnaeus), pigfish; *Pomolobius pseudoharengus* (Wilson), alewife

Other Localities: Woods Hole, Massachusetts; Beaufort, North Carolina; Bermuda; Dry Tortugas, Florida

Family HEMURIDAE

20. *Sterrhurus floridensis* Manter, 1934

Hosts: Holocentrus ascensionis (Osbeck), squirrel fish, in 2 of 3; **Malacanthus plumieri* (Bloch), sandfish, in 1 of 4; and *Scorpaena plumieri* Bloch, scorpion fish, in 1 of 1

Other Hosts: 19 species from several families

Localities: Nassau and Eleuthera, Bahamas

Other Localities: Dry Tortugas, Florida; Bermuda; Grand Isle, Louisiana (unpublished data); Mexican coast of Gulf of Mexico (unpublished data)

21. *Ectenurus virgulus* Linton, 1910

*Host: *Holocentrus ascensionis* (Osbeck), squirrel fish in 1 of 3

Other Hosts: Platophrys ocellatus (Agassiz), eyed flounder, *Harengula cupeola* Cuvier, big-eyed sardine; *Trachurops crumenophthalmas* (Bloch), goggle-eyed scad

Other Localities: Woods Hole, Massachusetts; Dry Tortugas, Florida

A single specimen of a trematode tentatively identified as *E. virgulus* was recovered from a squirrel fish collected in Nassau Harbor. Though this specimen is approximately twice the size of Linton's type species and the eggs are considerably larger, $26\mu \times 16\mu$ compared to $17\mu \times 8\mu$, the body proportions are the same. Rather than describe a new species

on the basis of the single specimen, it has been decided to expand the limits of the species to a maximum of 6.6 mm in length and the size of the ova to $26\mu \times 16\mu$.

22. *Brachadena pyriformis* Linton, 1910

Host: **Haemulon sciurus* (Shaw), blue-striped grunt

Other Hosts: Large number of fishes of several families

Other Localities: Woods Hole, Massachusetts; Beaufort, North Carolina; Dry Tortugas, Florida; California

23. *Distomum fenestratum* Linton

Host: *Pseudupeneus maculatus* (Bloch), spotted goatfish

Other Hosts: Numerous fishes of many families

Previously Known Localities: Woods Hole, Massachusetts; Dry Tortugas, Florida; Grand Isle and Mississippi delta of Louisiana (unpublished data)

COMPARISON OF THE TREMATODES OF TORTUGAS AND THE BAHAMAS

Manter (1947, 1955), and Hanson (1950) have remarked upon the great similarity between the trematode faunas of Tortugas and Bermuda. Hanson (1950) lists 28 species common to both areas. This is 19.1 per cent of the 147 shallow-water trematodes present at Tortugas. This figure is based on considerable collecting by Linton in the early part of the century, plus the "Barker collection" studied by Hanson.

The very limited present study has shown 20 species (13.6 per cent) of the Tortugas fauna to be present in the Bahama Islands. Of perhaps even more interest is the fact that these 20 species represent 91.3 per cent of the trematodes collected in the Bahamas. One of the two species not found at the Dry Tortugas, identified as *Multitestis rotundum*, is represented by a single specimen. This is not as good a specimen as would be desired for establishing the range extension from the Texas coast, where the species was described, to the Bahamas. The second species found in the Bahamas but not at the Dry Tortugas is *Helicometrina elongata*. Numerous examples of this worm were recovered from an ocellated flounder collected in Nassau harbor. This trematode has not previously been reported from the Atlantic Ocean or the Gulf of Mexico. It was described from the California coast, where it occurs in several species of fish of two families. The third species, *Rhipidocotyle capitatum*, may prove to be synonymous with *R. nagatyi*, in which case it will be another species common to the two areas.

It is believed that the trematode fauna of the Bahamas will prove to be almost identical to that of Tortugas, much more similar than are the faunas of Bermuda and Tortugas, since 13.6 per cent of the shallow-water flukes known from Tortugas were found at the Bahamas by examining only 25 fish of 15 species (Table 1). A further indication of the close similarity is that 86.9 per cent of the trematodes recovered from the Bahamas are also known from the Dry Tortugas. In comparison, only seven species are now known to be shared by the Bahama Islands and Bermuda. Additional collections will almost certainly show a closer relation between the faunas of the Bahamas and Bermuda, but it is strongly believed that further study will show an even closer relationship between the Bahama Islands and the Dry Tortugas.

SUMMARY

During late February and early March, 1952, 25 fish of 17 species were collected from the areas of Nassau and Eleuthera, British West Indies, and examined for digenetic trematodes. Fifteen of the species and all but four individuals harbored digenetic trematodes. Those species found to be negative were *Abudefduf saxatilis* and *Dules subligarius*. Sixteen new host records were listed, and a new record for the Atlantic Ocean of a species described from the Pacific coast of California was cited.

A close relationship between the trematode faunas of the Dry Tortugas, Florida, and the Bahama Islands was found; a much closer relationship than occurs between the faunas of the Dry Tortugas and Bermuda or the faunas of the Bahama Islands and Bermuda.

TABLE 1
DIGENETIC TREMATODES OF SHALLOW WATER FISHES COMMON TO
DRY TORTUGAS AND BAHAMAS AND BERMUDA AND BAHAMAS

Common to Dry Tortugas and Bahamas	
1. Rhipidocotyle barracudae	11. Stephanostomum casum
2. Lepocreadium trulla	12. S. microstephanum
3. Lepidapedon levenseni	13. Tergestia pectinata
4. Pseudopecoeloides gracilis	14. Haplospilanchnus adacutus
5. Neopecoelus scorpaenae	15. Genolopa ampullacea
6. N. holocentri	16. Siphodera vinaledwardsii
7. Hamacreadium mutabile	17. Sterrhurus floridensis
8. Helicometra execta	18. Ectenurus virgulus
9. Stenopera equilata	19. Brachadena pyriformis
10. Helicometrina nimia	20. Distomum fenestratum
Common to Bermuda and Bahamas	
1. Lepocreadium trulla	4. Genolopa ampullacea
2. Stephanostomum casum	5. Lepidapedon levenseni
3. Siphodera vinaledwardsii	6. Sterrhurus floridensis
7. Distomum fenestratum	

HOST LIST			
Host	No. examined	Trematodes	
1. <i>Sphyraena barracuda</i> (Walbaum) great barracuda	2	<i>Rhipidocotyle barracudae</i>	Manter, 1940
2. <i>Holocentrus ascensionis</i> (Osbeck) squirrel fish	3	* <i>Rhipidocotyle capitatum</i> (Linton, 1940)	Manter, 1947
		* <i>Neopecoelus holocentri</i>	Manter, 1947
		* <i>Lepidapedon levenseni</i> (Linton, 1907)	Manter, 1947
		* <i>Stenopera equilata</i>	Manter, 1933
		* <i>Stephanostomum microstephanum</i>	Manter, 1934
		* <i>Sterrhurus floridensis</i>	Manter, 1934
		* <i>Ectenurus virgulus</i>	Linton, 1910
3. <i>Pseudupeneus maculatus</i> (Bloch) spotted goat fish	1	<i>Distomum fenestratum</i>	Linton
4. <i>Trachurops crumenophthalmas</i> (Bloch) goggle-eyed scad	1	<i>Tergestia pectinata</i> (Linton, 1905)	Manter, 1940
		<i>Pseudopecoeloides gracilis</i>	Manter, 1947
5. <i>Cephalopholis fulvus</i> (Linnaeus) coney	2	* <i>Helicometrina nimia</i>	Linton, 1910
6. <i>Epinephelus adscensionis</i> (Osbeck) rock hind	1	Unidentified?	
7. <i>Dules subligarius</i> (Cope) belted sandfish	1	Negative	
8. <i>Lutjanus analis</i> (Cuvier and Valenciennes) mutton fish	1	<i>Hamacreadium mutabile</i>	Linton, 1910
		* <i>Helicometrina nimia</i>	Linton, 1910
9. <i>Ocyurus chrysurus</i> (Bloch) yellowtail	1	<i>Siphodera vinaledwardsii</i> (Linton, 1889)	Linton, 1910
		<i>Hamacreadium mutabile</i>	Linton, 1910
10. <i>Haemulon sciurus</i> (Shaw) blue-striped grunt	1	<i>Genelopa ampullacea</i>	Linton, 1910
		* <i>Brachadena pyriformis</i>	Linton, 1910
		Unidentified opecoelid	
11. <i>Calamus calamus</i> (Cuvier and Valenciennes) saucer-eye porgy	1	<i>Helicometrina nimia</i>	Linton, 1910
		<i>Lepocreadium trulla</i> (Linton, 1907)	Linton, 1910
		* <i>Multitestis rotundum</i>	Sparks, 1954
12. <i>Abudefduf saxatilis</i> (Linnaeus) sergeant major	2	Negative	
13. <i>Novaculichthys rosipes</i> (Jordan and Gilbert) rosy razor-fish	1	<i>Helicometra</i>	sp.
14. <i>Scarus croicensis</i> (Bloch) Bahama parrotfish	1	* <i>Haplospilanchnus adacutus</i>	Manter, 1937
15. <i>Scorpaena plumieri</i> Bloch West Indian scorpion fish	1	<i>Helicometrina nimia</i>	Linton, 1910
		* <i>Neopecoelus scorpaenae</i>	Manter, 1947
*New host record		<i>Sterrhurus floridensis</i>	Manter, 1934

HOST LIST		
Host	No. examined	Trematodes
16. <i>Malacanthus plumieri</i> (Bloch) sandfish	4	* <i>Sterrhurus floridensis</i> Manter, 1934 * <i>Helicometrina nimia</i> Linton, 1910 * <i>Helicometra execta</i> Linton, 1910 * <i>Stephanostomum casum</i> (Linton, 1910) MacFarlane, 1936
17. <i>Ancylopsetta quadrocellata</i> Gill ocellated fluke *New host record	1	* <i>Helicometrina elongata</i> , Noble & Park, 1937

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EFFECTS OF STORMS ON THE SHALLOW-WATER FISH FAUNA OF SOUTHERN FLORIDA WITH NEW RECORDS OF FISHES FROM FLORIDA¹

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ABSTRACT

The passage of storms or persistence of onshore winds result in turbulent conditions in shallow, inshore waters and in fish kills of varying intensity. Species of fishes not normally found in shallow exposed locations may become established in such a habitat during periods or seasons of calm weather. These species are unable to withstand turbulent conditions and are killed apparently due to erosion of gill filaments by accumulated sediments. The importance of storms as a limiting factor in the shoreward distribution of many fishes is noted. The specimens collected after a storm kill in the region of Miami, Florida, include several species previously unrecorded or of rare occurrence in Florida waters. *Otophidium grayi* is shown to be a species distinct from *O. omostigmum* with which it had been previously synonymized.

INTRODUCTION

Large kills of marine fishes are often recorded in the literature. They are associated with diverse causes, among them shifts in ocean currents (e.g., El Niño along the Peruvian coast, see Sverdrup *et al.*, 1942: 704-705), turnover of stagnant bottom waters of fjords or other similarly isolated basins, abrupt changes in water temperature (Gunter, 1941, 1952; Gunter and Hildebrand, 1951), outbreaks of red tide (Ingle and deSilva, 1955, and papers cited therein), and volcanic activity (Gosline *et al.* 1954; Gosline, 1954). For a discussion of these problems the reader is referred to the numerous references cited by Geyer (1950).

Less spectacular but more frequent are kills that follow several days or weeks of steady onshore winds in regions where this is not the usual condition. Normally quiet waters over broad shoals and behind sand bars are hit by heavy seas and, at such times, quantities of sand and other sediments are stirred up and carried in suspension beyond their normal limits of deposition. In the Florida region, passage of hurricanes and lesser tropical disturbances are marked by accumulations of dead fish along the beaches. Marco Beach near Marco, and Sanibel Island near Fort Myers, both on the western coast of Florida, are noted for such occurrences. Similarly, large kills have been noted in these regions after unusually severe cold spells (Storey and Gudger, 1936; Storey, 1937).

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Life in the upper segment of the eulittoral zone is precarious at best and successful forms must be tolerant of rapid and drastic environmental change. Relatively few species of fishes spend their entire juvenile and adult life in this zone; many more occur here as juveniles but move into somewhat deeper water as they mature. Among the fishes that live successfully in the shoal waters of southern Florida are several species of *Harengula* (Clupeidae), two species of *Eucinostomus* (Gerridae), four cyprinodontids (*Floridichthys carpio*, *Cyprinodon variegatus*, *Fundulus grandis* and *F. similis*), the molly (*Mollienesia latipinna*), *Abudefduf saxatilis* (Pomacentridae), several blennioid fishes (*Paraclinus*), numerous gobies (especially those of the genera *Gobiosoma*, *Bathygobius* and *Lophogobius*) and juveniles of a filefish (*Stephanolepis hispidus*), the grey (*Lutjanus griseus*) and schoolmaster snappers (*L. apodus*), the permit (*Trachinotus falcatus*), and several jacks (*Caranx*). They abound at the water's edge and move back and forth with the changing tides.

It is important to note that such species are not often noted in lists of fishes killed by sudden environmental fluctuation. At Marco and Sanibel, broad expanses of shallow water lie adjacent to the beach and into such marginal habitat forage numerous species normally associated with somewhat deeper water. Also, many bottom forms from adjacent deeper regions become established in these waters during prolonged periods of favorable conditions. Such forms unknowingly court disaster and are the ones killed by freezes and storms, trapped as they are in suddenly adverse habitat.

The importance of sudden freezes as a limiting factor in the establishment of species in shoal water has been amply discussed in the literature cited above and by Geyer (1950). That tropical storms or merely the occurrence of strong or steady onshore winds constitute another important limiting factor has not been noted. Sand and other suspended sediments accumulate in the gill chambers of fishes. Should roiled conditions persist, death occurs either directly due to the destruction of gill filaments or by the weakened animal being swept onto the beach.

An opportunity to study this phenomenon on a small scale came in October of 1956 in the Miami region. From October 6th to 15th, steady onshore winds of 30 miles per hour, with gusts considerably higher, buffeted the southeastern coast of Florida. There was no drop in temperature. Key Biscayne, outermost of several islands connected to the mainland at Miami by Rickenbacker Causeway, and near to

the Marine Laboratory on Virginia Key, was the study site.

OBSERVATIONS

The beach between the lighthouse and Crandon Park was very badly eroded. Mr. and Mrs. John D. Gill notified the laboratory that fish were drifting ashore and Durbin Tabb and Alan Moffet investigated and obtained the specimens reported on below. At this site a slightly submerged offshore bar traps several hundred yards of deeper water (to 20 feet or more) between itself and the beach. This area, protected from normal seas, and covered with weed beds, was severely roiled with sediments from both sides. Some of the fishes were still alive when collected on the beach but all had the gill chambers filled with sand and the filaments themselves were very frayed. None of the common shore species (see listing above) were collected. Since they could scarcely move from the area it seems likely that they were unaffected. Of the species taken, only the puffer, *Spheroides spengleri*, commonly frequents the water's edge although it prefers more sheltered sites in muddy and weedy rather than sandy environs. The other species would be expected in somewhat deeper water several hundred feet or farther from shore.

Twenty-four specimens representing 16 species were collected (number of specimens, if more than one, in parentheses): *Aulostomus maculatus* Valenciennes, *Apogon binotatus* (Poey) (4), *Lutjanus analis* (Valenciennes), *Calamus bojanado* (Bloch and Schneider), *Chaetodon striatus* Linnaeus, *Chaetodon ocellatus* (Bloch), *Holacanthus isabelita* (Jordan and Rutter), *Lachnolaimus maximus* (Walbaum) (4), *Acanthurus bahianus* Castelnau (2), *Otophidium grayi* Fowler, *Scorpaenodes caribbaeus* Meek and Hildebrand, *Monacanthus tuckeri* Bean, *Chilomycterus antillarum* (Jordan and Rutter), *Canthigaster rostratus* (Bloch) (2), *Spheroides spengleri* (Bloch) and *Lophiocharon tenebrosus* (Poey). Several of them are new to the known Florida fauna or only rarely noted. They are discussed below.

Otophidium grayi.—Only three species of cusk eels in Florida waters have prominent dark marking on the body: *Otophidium welshi*, *O. omostigmum* and *O. grayi*. *O. welshi* is easily distinguished by the three dark stripes which it possesses, one along the base of the dorsal fin, a second along the lateral line and a third and somewhat ill-defined stripe on the mid side. The other two species are blotched. Recently, Briggs and Caldwell (1955) combined *grayi* and *omostigmum* as variants of a single species. Several factors precipitated this action.

The unique type of *omostigmum* was a small specimen whereas the extant material of *grayi* were all considerably larger, an illustration of the type published subsequent to the description was poorly executed, and the type is no longer in good condition.

TABLE 1
COMPARISON OF *Otophidium omostigmum* AND *O. grayi*.

Character	<i>omostigmum</i>	<i>grayi</i>
Anal-fin color	largely black	clear with black margin posteriorly
Insertion of dorsal fin	well behind opercular flap	over tip of opercle
Pigment in dorsal fin	blotches submarginal	blotches in fin membrane and along margin
Pectoral fin	pointed, the upper rays longest except for first two	rounded, the central rays longest
Pattern on occiput and opercle	unmarked	variously blotched with dark
Humeral spot	large, black and sharply defined. Most striking feature of color pattern	absent or small and ill-defined. Not so prominent as other blotches
Diameter of eye	longer than snout. Enters head less than 3 times	shorter than snout, enters head length more than 4 times (usually about 5)
Eye diameter into distance from occiput to dorsal insertion	less than 2 times	2 or more times
Infraorbital canal	pores easily seen, suborbital bones cavernous	pores very small, suborbital bones not visible externally
Gas bladder	with large funnel shaped opening caudally	with small ventral slit or long tube-like process from ventral surface
Pectoral rays	16-18	20-22
Dorsal-fin rays	99-104 (2 spec.)	130-136 (4 spec.)
Anal-fin rays	85 (2 spec.)	99-109 (4 spec.)
Scalation above lateral line on anterior part of body	overlapping; in regular rows	<i>Anguilla</i> -like; rows staggered.

Study of the Miami specimen of *grayi* (UMML 49:279) and a second specimen of *omostigmum* (UMML 49:440) suggested differences beyond that expected in infraspecific variation. The writer is indebted to John C. Briggs and David K. Caldwell for a loan of speci-

mens of *grayi* in the collection at the University of Florida (UF), to Royal D. Suttkus of Tulane University for the opportunity to examine a specimen of *omostigum* in his care (TU) and for providing ray counts, and to Thomas J. McKenney of The Marine Laboratory for notes on the holotype of *omostigum* at the United States National Museum (USNM 29670). I am especially grateful to Giles W. Mead of the Fish and Wildlife Service for additional remarks on the holotype and for generously checking distinguishing features of the two species in unsorted collections from the Gulf of Mexico.

The difference between *omostigum* and *grayi* are summarized in Table 1. Differences in pigmentation, body shape and in the gas bladder may best be seen in Figure 1. Material examined includes (number of specimens and range of standard lengths in millimeters in parentheses): three specimens of *omostigum*, USNM 29670 (1, 91—holotype), UMML 49:440 (1, 90), TU 10924 (1, 125) and four specimens of *grayi*, UMML 49:279 (1, 270), UF 4572 (2, 248-256) and UF 4485 (1, 160). Additional material was checked by Dr. Mead as noted above.

O. omostigum is a small species previously reported only from the type specimen (taken off Pensacola, Florida). The Tulane specimen is from Campeche Bay (OREGON station 1058; 18° 45' N, 93° 20' W) while the Miami specimen is from the region between Jacksonville, Florida, and Brunswick, Georgia, along the 25.50 fathom contour. The color pattern seems quite constant, its most striking components being the large and intensely black humeral spot, the heavily pigmented anal fin and a few large, ill-defined dark blotches on the upper portion of the body. The holotype is in poor condition; the body is hard and brittle and the fins broken. Nonetheless the humeral spot is still discernible. Fortunately, Jordan and Gilbert (1882:301-302) described the pattern and in particular recorded the anal fin as largely black. Goode and Bean (1895: fig. 305) later figured the type but the anal fin, perhaps faded by that time, was indicated as uncolored and other diagnostic features are not evident. Their figure was reproduced by Jordan and Evermann (1900: pl. 354) but these writers (1898: 2490) persist in noting the anal fin as black.

O. grayi exhibits much variation in color pattern, a fact that would lead one to incorrectly suspect the constancy of color pattern in other cusk eels, as *omostigum* and *welshi*. The correlation of morphological differences with those of pattern suffice to distinguish them.

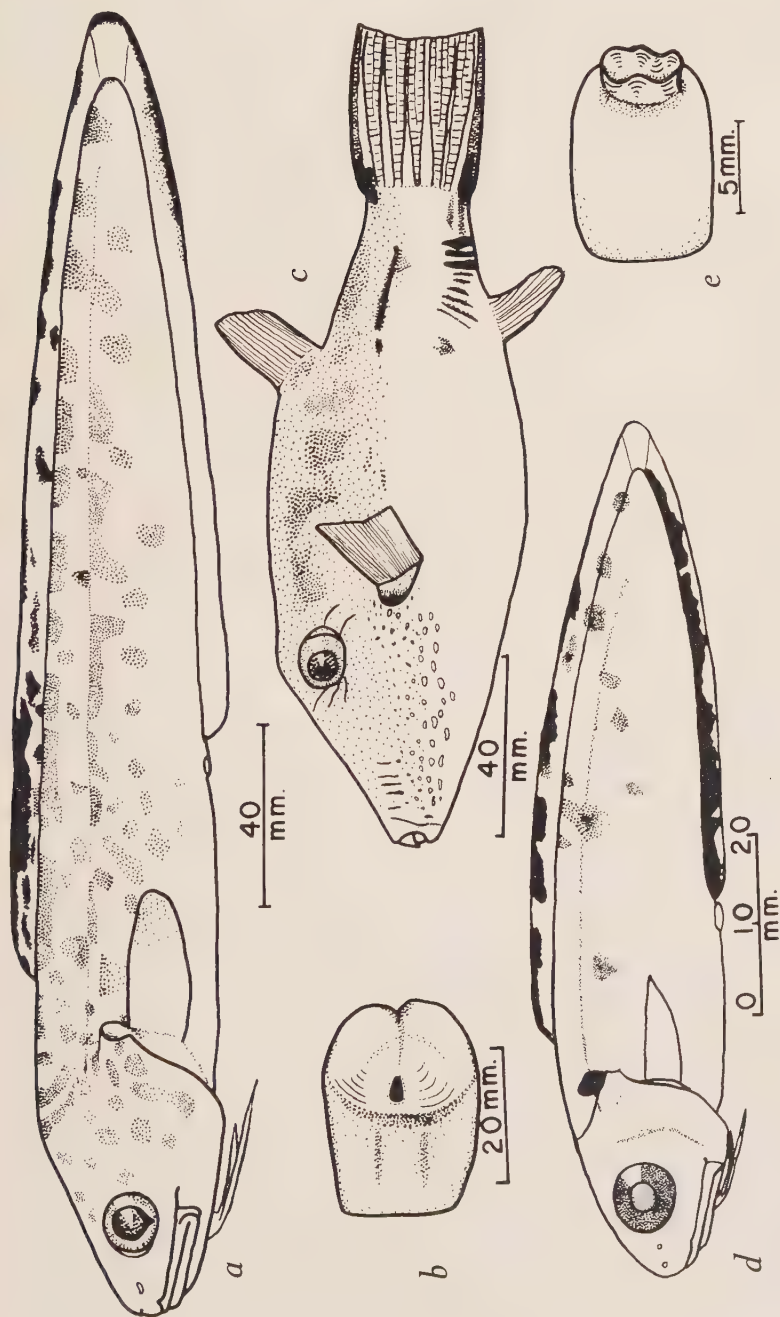


FIGURE 1. a, *Otophidium grayi* (UMML 49:279, S. L. = 270 mm). b, ventral view of gas bladder of *O. grayi* (anterior end to left). c, *Canthigaster rostratus* (UMML 49:122, S. L. = 72 mm). d, *Otophidium omostigmum* (UMML 49:440, S. L. = 90 mm). e, ventral view of gas bladder of *O. omostigmum* (anterior end to left).

Both the figure of the holotype (Fowler, 1948: fig. 1) and that in Briggs and Caldwell (1955: fig. 4) clearly demonstrate the prominent blotches on the head and body, the spotted dorsal fin, the rounded pectoral fin and the unpigmented anal fin, all diagnostic features of *grayi*. The Miami specimen, a female, is illustrated in Figure 1a. It differs from the other samples in having a more elongate body, lower vertical fins, more numerous and much smaller spots on the body and a longer gas bladder with an open slit on its posterior ventral surface (see Figure 1b). The possibility may not be ruled out that a third species of spotted cusk eel exists in the warmer waters off southern Florida.

Scorpaenodes caribbaeus.—The one juvenile, 56.8 mm in standard length (UMML 49: 520), agrees well with the description by Ginsburg (1953: 38-40). Elements on the upper arm of the first gill arch number seven. The interorbital ridges are well developed and end in spines. There are three spines in a row below the suborbital ridge. Many of the head spines have dark brown fleshy tabs at their tips. A distinct dark brown blotch marks the distal two-thirds of the spinous dorsal membrane between spines 9 and 12. Counts are: dorsal rays, XII, I-9; anal rays, III, 5 (second spine very well developed, 11.3 mm); pectoral rays, 19-19; pelvic rays, I, 5-I, 5; lateral-line scales, 42; head length, 25.3 mm, longest pectoral ray, 18.6 mm. Palatine teeth are absent. There is a small slit behind the fourth gill arch. The scales are ctenoid and the inner surface of the pectoral fin and its axil are spotted with brown. The species has not heretofore been recorded from Florida waters.

Monacanthus tuckeri.—Longley and Hildebrand's (1941: 296-297) report on Tortugas material is the only previous mention of *tuckeri* in Florida. It has perhaps been mistaken for *M. ciliatus*, a common species. A brief description and counts are provided by Clark (1950) for specimens from Bimini in the western Bahamas.

The following counts and measurements were made from the single storm-killed individual (UMML 49: 522): standard length, 63.2 mm; head length, 19.4; eye diameter, 5.2; height of dorsal spine, 13.6; snout length, 15.4; depth of body at anus, 15.4; dorsal rays, 34; anal rays, 34; pectoral rays, 11-11. Small black cirri are scattered over the body. The dorsal spine has two well developed rows of recurved spines. There are four strong, recurved accessory spines at the base of the free portion of the ventral spine, two projecting spines are at

its tip and a pair of recurved spines lie on each side between the tip and the basal row of accessory spines. The species is distinguished from *ciliatus* at a glance by its slender body form.

Chilomycterus antillarum.— This burrfish is an addition to the known fish fauna of Florida. Color notes were recorded shortly after the specimen (UMML 49: 129) was picked up. The ventral portion of the iris is light orange (forming a ring about the pupil) The belly is generally dark. However, the fleshy processes on the ventral spines are light orange and the area around the vent is marked by fine yellow lines. The species is best characterized by the network of lines on the dorsum and sides that combine to form a series of hexagons of varying size. The lines themselves are dark brown becoming rust colored in certain areas while the interspaces are grey with a brownish tinge. All species of *Chilomycterus* are apparently marked by several very large dark spots. In *antillarum*, those above the pectoral fin have a rust-colored border. The gular region has yellow-orange vermiculations whereas the flesh covering the dorsal spines (especially cephalad) is olive-yellow. The nasal flaps, the caudal and anal fins and the distal portion of the pectoral fins are orange.

Specimens from the Bahamas have the hexagonal lines much broader and less well defined, and the hexagons are fewer. Curiously, Bahaman specimens of *C. schoepfi* also have their dorsal stripes broad and ill-defined.

Canthigaster rostratus.— The sharpnose puffer has been recorded from Florida waters only by Longley and Hildebrand (1941: 300-301). Two juveniles (UMML 49: 122), the largest of which is illustrated in Figure 1c, were taken in the collection under consideration. Recently, another juvenile (UMML 49: 515) was dip netted at the Causeway Terminal Yacht Basin at Miami Beach (again following a week of strong winds). Apparently it is truly uncommon on our coast for numerous shore collections in southern Florida have failed to reveal it whereas at Bimini harbor in the western Bahamas the writer and Vladimir Walters of the Lerner Marine Laboratory found it abundant in shallow water. For a description of this species see Clark (1950: 166).

Lophiocharon tenebrosus.— The single specimen of this antennariid has been deposited in the United States National Museum (USNM 174940). The species has not been recorded from Florida and indeed has not been taken since Poey described his unique example. Leonard

P. Schultz of the National Museum identified the specimen and is reporting on the status and relationships of the species elsewhere.

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The scope of the bibliography is limited in general to the area which includes the southeastern United States, the Gulf of Mexico, and the Caribbean, but papers of more general interest may be listed in cases where they have some special significance to the area.

The degree of comprehensiveness of the bibliography is to a large extent dependent upon the cooperation of workers in the Marine Sciences of this area. *It is therefore hoped that individuals and organizations will aid by sending copies of all relevant publications to the Editor.* Any omissions brought to the attention of the Editor will be included in subsequent issues.

It has been found convenient to use a modification of the classification used by the Journal du Conseil Bibliography for present purposes.

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